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ELECTRICAL PERFORMANCE TESTS FOR STORAGE OSCILLOSCOPES

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Prepared for:
U.S. Army Communications Electronics Command
Fort Monmouth, New Jersey 07703

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Abstract

Procedures were developed to test the electrical performance of a dc to 100 MHz storage oscilloscope for the purpose of evaluating samples submitted by electronic instrument manufacturers in response to specifications issued by the U.S. Army Communications-Electronics Command. The detailed, step-by-step test procedures are based on the specifications supplied by the Army and include sample data sheets and tables for the recording of interim data and final test results.

This report discusses the measurement principles and techniques underlying the most significant procedures. In addition, the sources of measurement uncertainty are discussed.

Key Words: acquisition memory; A/D converter; charge-coupled devices; digital storage oscilloscope; digital waveform recorder; flash converter; record length; sample/hold; test procedures; waveform processor; waveform sampling

1. Introduction

This report contains theory, measurement techniques, and detailed test procedures developed by the National Institute of Standards and Technology (NIST), formerly the National Bureau of Standards (NBS), for the U.S. Army Communications-Electronics Command (CECOM) to test the electrical performance of a storage oscilloscope that has a bandwidth from dc to 100 MHz. The test procedures are based on performance specifications supplied by CECOM, for use by the Army in their Test, Measurement, and Diagnostic Equipment (TMDE) Modernization Program to evaluate bid samples of candidate instruments. The report focuses only on the test procedures for electrical performance that can be carried out without access to the interior of the instruments under test. For the most part, the Army performance specifications represent performance levels attainable by modern storage oscilloscopes.

The main objective in developing the test procedures has been to provide measurement techniques which are accurate, repeatable, and simple to perform. Most importantly, the test procedures must be technically sound so as to provide an unbiased and objective evaluation of competitive instruments.

The test equipment chosen to perform these test procedures has been selected not only for the requirements of each individual test, but in a broader context of establishing a bid sample testing laboratory at CECOM. Thus, some equipment used in the test procedures may have better accuracy or greater capabilities than is necessary to test the storage oscilloscope.
This report is divided into three main sections: Introductory section 1 gives the background of the Army's TMDE Modernization Program and the scope of this

report. Section 2 describes the operating principles of analog and digital storage oscilloscopes. Section 3 gives further technical details and features of digital storage oscilloscopes (DSOs), and describes methods of evaluating their performance. Evaluation of measurement uncertainties is also discussed. The information in this section is intended to provide the theory and analysis necessary to support the actual detailed test procedures given in Appendix B. The step-by-step test procedures are to be used by the Army for evaluating bid samples to assure conformity with the set of Army specifications given in Appendix A. Included in Appendix B are samples of appropriate data sheets and tables for recording interim and final results.

Appendix C shows the design and characteristics of specialized fixtures that are used in some of the test procedures, and Appendix D lists all the test equipment and accessories required for conducting the test procedures. Although the test procedures described in this report were specifically designed for use by the Army TMDE Modernization Program, many of the tests can be considered generic in nature and perhaps could serve as the basis of an industry standard for testing the performance of commercial storage oscilloscopes.

1.1 Background

The Department of the Army has undertaken a Test, Measurement, and Diagnostic Equipment (TMDE) Modernization Program. The general goal of this program is to provide TMDE for the Army and eliminate the proliferation of numerous types and models of such equipment in order to improve the efficiency of equipment maintenance. Specifically, the intent of the TMDE Modernization Program is to:

1. Introduce a minimum ensemble of different types and models of up-to-date TMDE into the Army inventory,

2. Replace multiple generic types of TMDE with a single new type, where feasible.

3. Periodically assess the Army TMDE inventory to identify individual or families of TMDE that require replacement.

The acquisition of new TMDE items progresses through a two-step invitation-for-bid procedure. The first step begins with letter requests for bid samples that are released to potential offerors . The offeror has a period of 60 days to analyze the solication requirements and send bid sample equipment to CECOM for testing. The equipment is then evaluated for performance, useability, maintainability, workmanship, ease of calibration, military suitability, safety, and environmental capability. After the bid sample testing, only the offerors with test equipment that meets the solicitation requirements are invited to submit bids. The second step occurs when the bids are received, evaluated, and the lowest responsive bidder is awarded the contract. This procurement procedure is believed by the Army to provide reliable and maintainable test equipment with superior performance characteristics for support of weapons systems. Bid-sample equipment evaluation requires an

established set of test procedures which can objectively determine conformity with the specifications. Unlike some evaluations such as safety and workmanship, which are more general and widely applicable, test procedures for electrical performance are by necessity specification specific. That is, for each particular electrical performance specification there must be a test procedure. Although some equipment manufacturers provide performance check procedures for purposes of incoming inspection, or readjustment to specifications, there is a lack of generic test methods applicable to various classes of equipment that can be directly and objectively used by the Army. Before bid-sample testing can proceed, appropriate test procedures must be developed and validated. Therefore, this report describes the specific test procedures developed by NIST for the Army to perform bid-sample testing of commercial storage oscilloscopes.

1.2 Scope of this report

Although this report addresses the test procedures developed for a storage oscilloscope (Appendix B), a brief review of a conventional, non-storage oscilloscope may be in order since many of the features of storage oscilloscopes are found in conventional oscilloscopes. In addition, many of the test procedures that are applicable for conventional oscilloscopes also apply to storage-type oscilloscopes.

Storage oscilloscopes are usually of two types:

1. Analog storage oscilloscopes which can also function as conventional (non-storage) analog scopes.

2. Digital storage oscilloscopes (DSOs).

The typical analog storage oscilloscope contains a storage cathode-ray tube (CRT) which has a number of storage electrodes not found in a conventional CRT. The operation of these electrodes is controlled by various storage control and storage display circuits. Thus, the analog storage scope is considerably more complicated than the conventional non-storage scope. However, the analog storage scope is very versatile, since it can be operated either as a storage scope or as a non-storage scope (using front panel switches). See [1] for a description of the operation of a modern analog storage oscilloscope.

In DSOs, digital technology is used to sample and digitize the waveform to be displayed and store the waveform in a semiconductor memory. The contents of the digital memory are then reconverted to analog form and displayed.

Both the storage-CRT oscilloscope design and the digital storage oscilloscope (DSO) design have strengths and weaknesses, in terms of performance, for various applications. The significant advantages of each type are as follows:

Analog storage oscilloscopes

- Simple to operate, particularly for trouble-shooting analog circuits.
- Fast update rate for slowly changing repetitive waveforms.
- Single-shot presentation of short pulses or intervals (particularly <5 ns) with better accuracy and detail than possible with DSOs. Pulses as short as 700 ps can be captured.

Digital storage oscilloscopes

- Most DSOs can display pre-trigger signals without the use of signal delay lines.
- DSOs are programmable and can communicate with other instruments via an IEEE-488 bus. This facility enhances the capability of automated test systems.
- Waveforms can be compared, analyzed and manipulated. Capabilities include waveform averaging to reduce noise and ripple, and automatic waveform parameter measurement.
- Effective bandwith does not descrease with age unlike storage CRTs where the effective writing speed decreases with age.

2. Oscilloscope Operating Principles

2.1 Conventional (analog) oscilloscopes

Figure 2.1 shows a basic block diagram for conventional oscilloscopes. The cathode ray tube (CRT) is shown on the right-hand side of the figure. The electron gun assembly generally consists of a cathode (C), control grid (G), pre-accelerating anode (A_1), focusing anode (F), and accelerating anode (A_2), These cylindrically shaped electrodes perform the functions of emitting, pre-accelerating, and focusing the electron beam. Anode A_2 accelerates the focused beam which then impinges on the fluorescent screen causing it to emit light. The magnitude of the beam current is controlled by the control grid/cathode voltage. A "push-pull" voltage V applied to either the vertical deflection plates (VP) or horizontal deflection plates (HP) causes the beam to be deflected vertically or horizontally, respectively. The intensity of the "writing" on the screen is determined by the energy of the electrons striking the screen and the number of electrons per unit area of the screen. Increasing either quantity increases the luminous intensity. Increasing the writing speed, i.e., increasing dV/dt, decreases the concentration of the electrons in any area traversed by the electron beam, and causes the luminous trace to be less intense. All cathode ray tubes used in today's oscilloscopes have electrodes for post-deflection acceleration (A_3). This permits the pre-deflection acceleration by A_2 to be decreased without decreasing the trace intensity. The resulting lower electron velocity thus increases the vertical and horizontal deflection sensitivity.

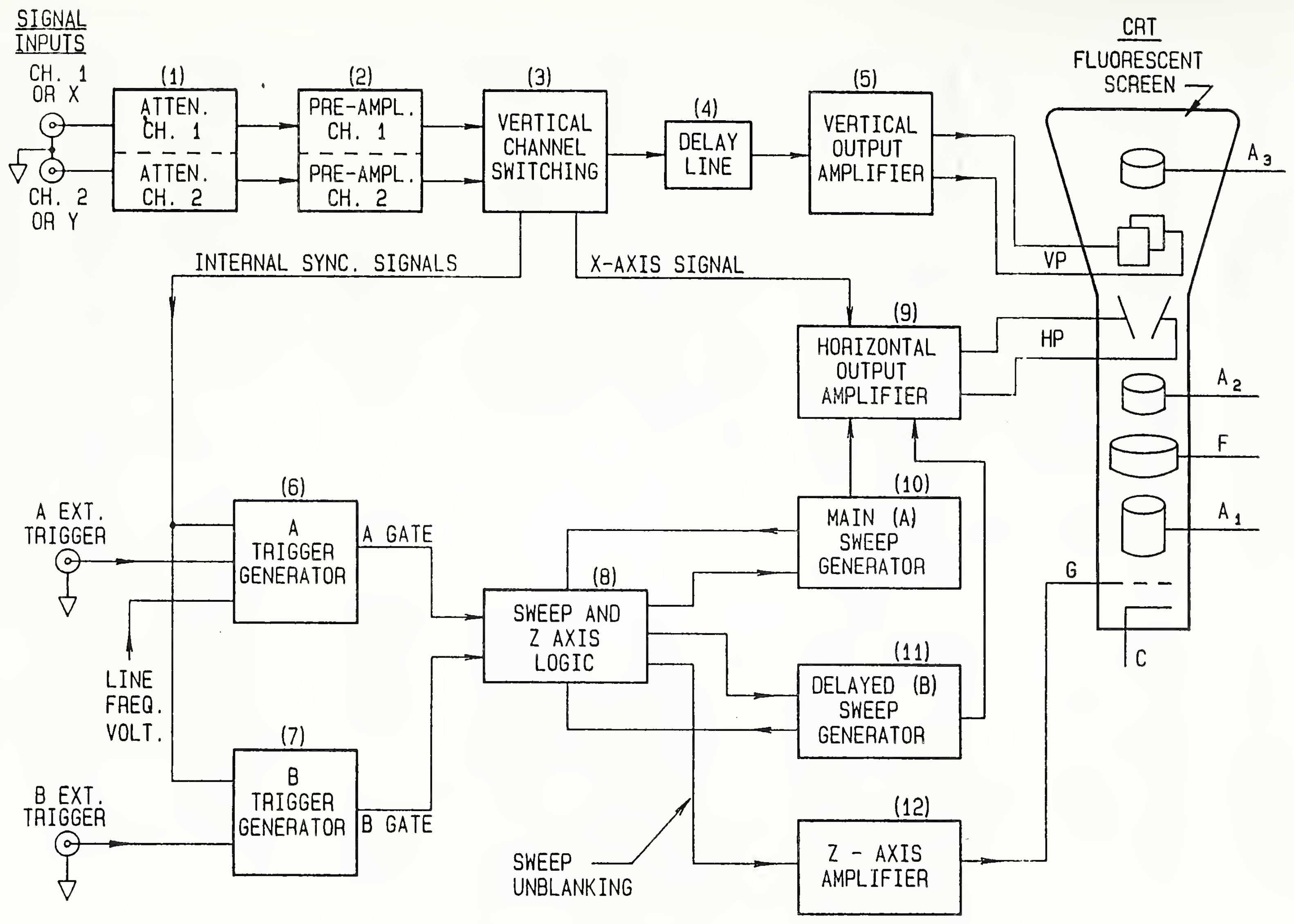

Figure 2.1 Basic conventional analog oscilloscope block diagram

Not shown is a CRT element for astigmatism control (similar to the focus control), and current coils for H-axis ("trace rotation") and Y-axis alignments. Power supplies have also been omitted from the figure.

As indicated in section 1.2, analog storage oscilloscopes incorporate a storage CRT into an otherwise conventional, non-storage oscilloscope. Storage CRTs have the ability to retain and display the image of an electrical waveform on the tube face after the input waveform ceases to exist. In analog storage scopes, the image intensity and image retention time (persistence) are selectable by front panel controls. Also, the storage mode of operation can be turned off so that the CRT functions as a conventional (non-storage) tube.

The waveform to be observed is applied to either Channel 1 (CH.1) or Channel 2 (CH.2). The gain for each channel is set by its VOLTS/DIV control (attenuator setting). Channel selection is made via the vertical channel switching circuits (3). If signals are applied to both channels for comparison or addition, these modes of operation are also selected by (3). After pre-amplification, the input signal is delayed approximately 0.2 μs by delay line (4), amplified by push-pull amplifier (5), and applied to the VP. The purpose of the delay line is explained later.

Two common applications of oscilloscopes are the measurement of the phase difference between sine waves using Lissajous figures and to measure the instantaneous value of a waveform V(t) as a function of time. For a Lissajous figure, the two sine waves being compared are applied to the X (CH.1) and Y (CH.2) inputs with the X channel signal amplified by push-pull amplifier (9) and applied to the HP. Measuring V(t) requires that a linear sweep voltage be applied to (9). Sweep (sawtooth) waveforms can be obtained from either sweep generator (10) or (11). Sweeps A and B can be operated independently, or sweep A can be used to produce calibrated delays in the start of sweep B. The unblanking gate voltage is applied to the CRT grid G via the Z axis amplifier, and is timed to turn the electron beam on only when circuits (10) and (11) are generating voltages.

When operated independently, sweep generator A or B functions when trigger signals (short gates) are received from trigger generator A or B, respectively. These latter circuits may be activated by external triggers or by internal sync signals generated by the input signal selected in circuit (3).

There are two modes of operation when sweep B is functioning as a delayed sweep and sweep A is functioning as a <u>delaying</u> sweep. In the MIX mode, sweep A provides the first part of the sweep and, following the selected delay, sweep B provides the second part of the sweep. Sweep B is intensified more than sweep A. The sweep speeds of A and B are determined by the TIME/DIV settings for each sweep. In the A intensified mode (A INTEN), the displayed sweep rate is determined by the A TIME/DIV switch and an intensified portion appears on the display during the B SWEEP TIME. The intensified part of the sweep decreases as the B TIME/DIV is decreased.

The internal synchronizing (sync.) signal is derived from the leading edge of the waveform being displayed. Since it takes approximately 0.1 μs of time to

start the sweep and unblank the CRT beam, the leading edge of the waveform can only be seen on the CRT screen if the waveform is delayed. The delay line (4) provides this delay.

The A trigger holdoff adjustment (not shown in figure) provides control of holdoff time (delay time) between sweeps to obtain stable displays when triggering on aperiodic signals.

2.2 Digital storage oscilloscope (DSOs)

Figure 2.2 shows a simplified block diagram of a DSO. Function blocks (1), (8), (5) and (11), as well as the CRT (not shown), perform the same functions as their counterparts in analog oscilloscopes. However, the output amplifiers and the CRT have much lower bandwidth requirements than for analog scopes. Also, the amplifiers function as current-to-voltage converters, since the digital-to-analog converters (DACs) (4 and 10) have current outputs. Because of lower bandwidth requirements the CRT has higher reliability, greater precision, longer life, and costs less than the high frequency CRTs used in analog oscilloscopes. Moreover, unlike analog storage oscilloscopes, DSOs usually have the capability of digitizing and storing input data from two or more channels simultaneously.

The signal flow from the input circuits (1) to the CRT is described briefly as follows: The output waveforms from (1) are digitized by analog-to-digital converters (ADCs) (2), stored in acquisition memories (3), processed in the microprocessor (μP) system (7), and applied to vertical DAC (4), resulting in output voltages from (5) to the vertical deflection plates (VP in figure 2.1). At the same time that digital data words are applied to (4), digital words from (7) are applied to horizontal DAC (10) for the purpose of generating a sweep voltage from (11) to the horizontal deflection plates. Since the signals applied to the input channels are digitized and stored simultaneously, simultaneous events can be viewed one at a time, or at the same time using alternate sweeps. If Lissajous figure displays are desired, the data words applied to (4) represent the signal applied to channel 2, as before, and the data words applied to (10) represent the signal applied to channel 1, rather than a sweep voltage.

The current outputs of DACs (4) and (10) have step changes, corresponding to the input digital word changes. These steps also appear in the voltage outputs of amplifiers (5) and (11), resulting in a dot display of the waveform. If desired, the dots can be connected by employing integrating (vector generating) circuits that are in the amplifiers (under front panel control).

The μP system (7) usually includes several microprocessors: a system μP, a waveform processor, and (sometimes) a front panel processor. The system μP, under program direction, controls all functions of the scope and coordinates the functions of the other two microprocessors. Permanent programming, used to control the operating system, resides in a read-only memory (ROM). The waveform processor performs operations on data received from the acquisition memories (3), such as adding, multiplying, averaging, and interpolation of

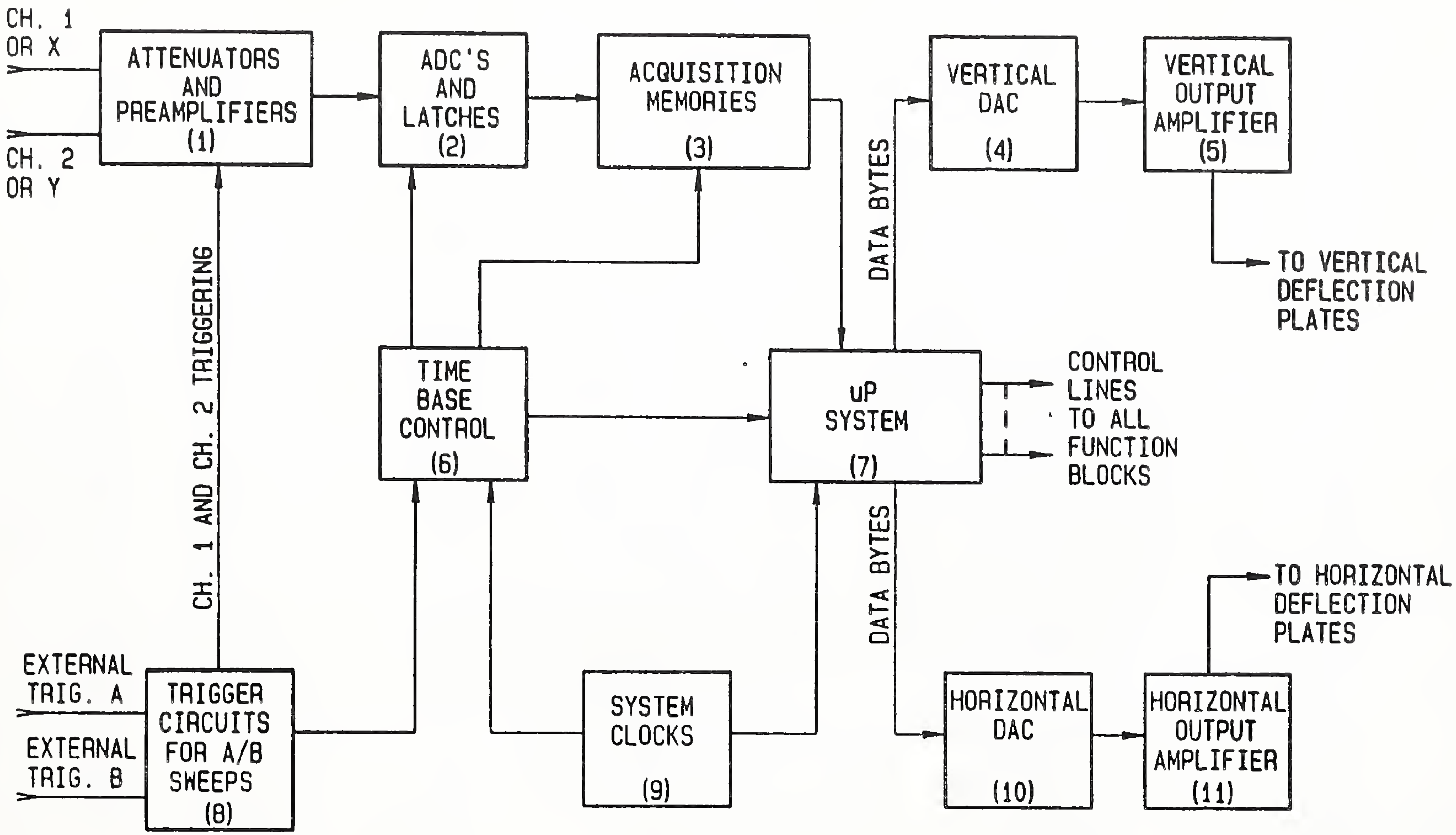

Figure 2.2 Simplified block diagram of a digital storage oscilloscope

waveform data. The front panel processor responds to changes in the control settings that are accessible from the front panel, and informs the system μP so that the operating state may be altered to match the requested changes.

The time base control (6) regulates the flow of data from the ADCs to the acquisition memories (3), and from (3) to (7). The ADCs are triggered or strobed by sampling clock pulses received from (6).

DSOs employ three methods of sampling: (1) real-time, (2) sequential equivalent-time (ET), and (3) random ET. These three sampling methods are illustrated in Figures 2.3, 2.4, and 2.5. With sequential and random ET sampling, the digitized waveform is reconstructed from samples taken on successive acquisition cycles. Real-time sampling, however, acquires all of the samples to be captured on one acquisition cycle; i.e., the samples are taken with one pass of the waveform [2,3]. ET sampling can only be used on repetitive waveforms, whereas real-time sampling is required for capturing single transients.

For real-time sampling, the signal is sampled and digitized continuously and clocked into the acquisition memory. In some instruments, e.g., those using charge-coupled devices (CCDs), the samples are temporarily stored in analog form and digitized later [3,4]. In the absence of a trigger, the memory fills with "pre-trigger" data samples, and after the memory is full, new data samples cause the oldest samples to be discarded or overwritten. After a trigger is received, "post-trigger" data is acquired and stored. The number of pre-trigger and post-trigger data samples retained is determined by the horizontal control settings. The trigger point is indicated by "T" in Figures 2.3, 2.4, and 2.5.

With sequential ET sampling, one point on the waveform is sampled for every acquisition cycle, i.e., after each trigger pulse. Each succeeding sample is delayed further from the trigger by the time interval Δt, causing points across the waveform to be sampled. The ET sampling rate is $1/\Delta t$. Since all samples are taken after the trigger, pre-trigger signals cannot be acquired.

Random ET sampling has some of the characteristics of both sequential ET and real-time sampling. As with sequential sampling, multiple acquisition cycles are required to acquire a signal, and the ET sampling rate is $1/\Delta t$, where Δt is the ET sampling interval. As with real-time sampling, the signal is sampled continuously at the sample clock frequency, and both pre-trigger and post-trigger samples are acquired during each acquisition cycle. Since the trigger is not synchronized with the system clocks, the sample times are random relative to the trigger time. In order to place the data samples in the proper memory locations, the time between the trigger and the following data sample must be accurately measured for each acquisition cycle. Then, since the sample clock period is accurately known, the times between the trigger and all pre- and post-trigger samples are also accurately known. Usually there are a number of samples per acquisition cycle.

For all three sampling methods, the minimum acceptable sampling rate, f_s, is dictated by the Nyquist sampling theorem, viz., $f_s/2$ must be greater than the highest input signal frequency component. Oversampling or undersampling a

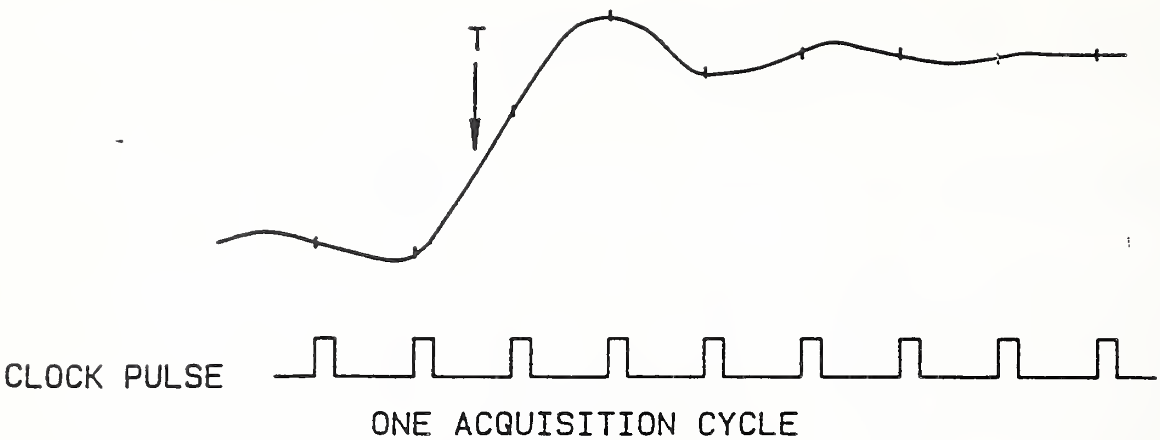

Figure 2.3. Real-time sampling. All samples, indicated by tick marks, are made on one pass (one acquisition cycle) of the waveform. The sample points may precede or follow the trigger point, T.

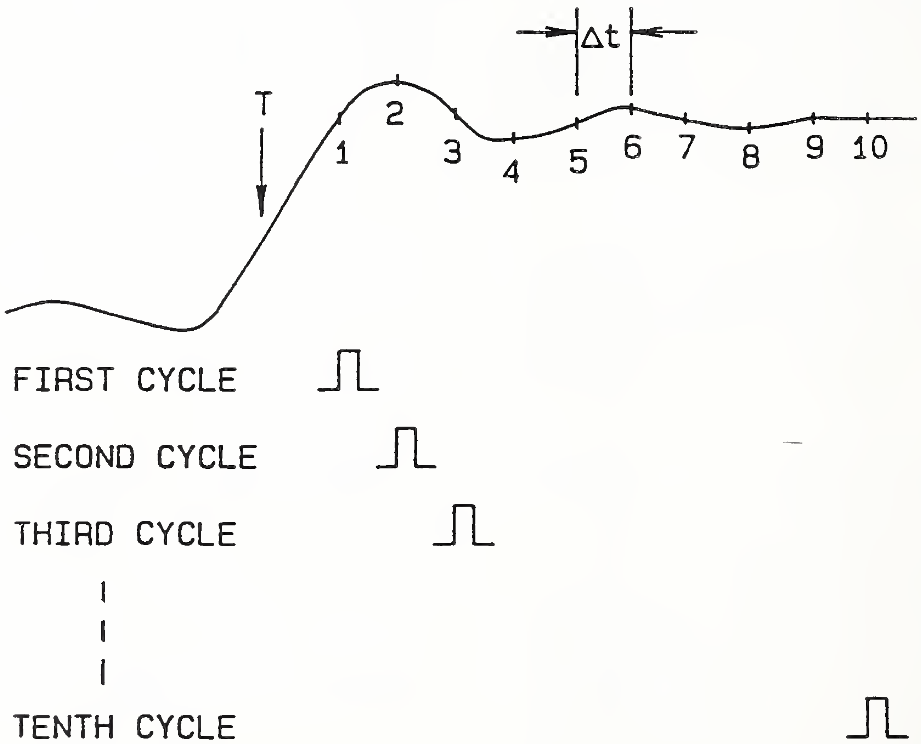

Figure 2.4. Sequential ET sampling. One point on the waveform is sampled after each trigger pulse (occurring at time T); e.g., samples 1, 2, 3,...are taken in successive acquisition cycles.

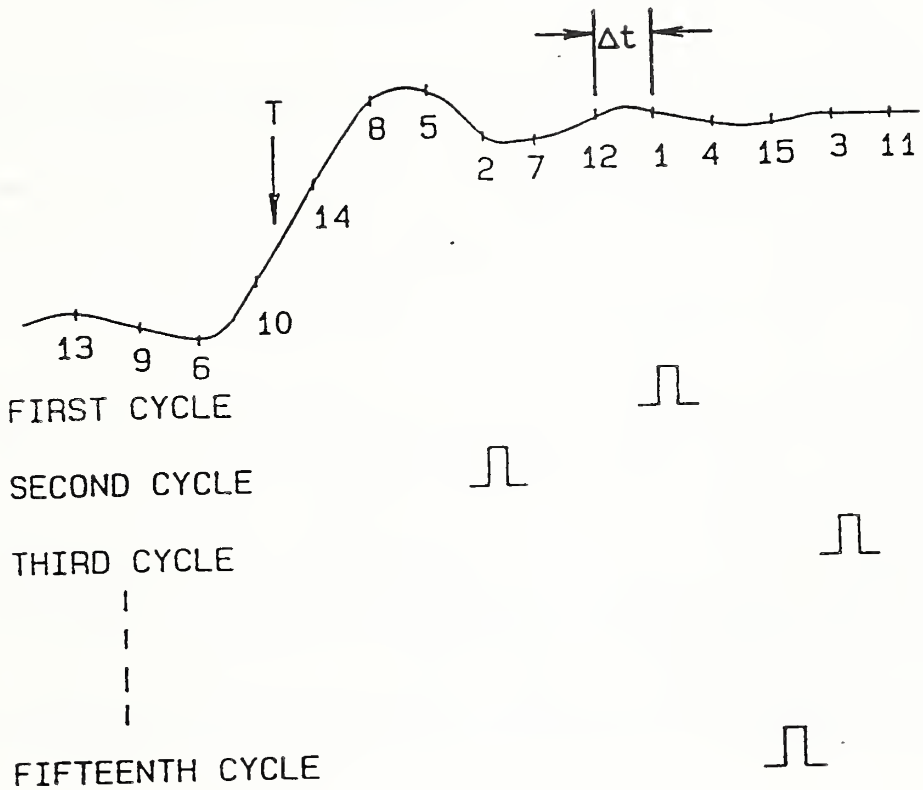

Figure 2.5. **Random ET sampling.** Numbers on data samples indicate the random sequence of the samples in successive acquisition cycles.

waveform refers to sampling at a rate greater than or less than the Nyquist rate, respectively. Undersampling causes aliasing, i.e., unwanted frequency components below the Nyquist frequency are generated.

The Nyquist requirement is easily met or exceeded (oversampling) with ET sampling since Δt can be made less than 10 ps (f_s > 100 gigasamples per second) for random sampling [5], and less than 0.25 ps (f_s > 4000 gigasamples per second) for sequential sampling [6]. Undersampling is more likely to result for real-time sampling, however, since 1-2 gigasamples per second is the current state-of-the-art maximum sampling rate. Note that, in practice, the ET sampling rate would be much higher than illustrated for the waveforms

in Figures 2.4 and 2.5. Also, more real-time samples are required to accurately reproduce a waveform than are shown in Figure 2.3. A specific example of reconstructing a waveform using sampling rates of approximately 1x and 2x the Nyquist rate will be discussed in section 3.1.2.6.

3. Storage Oscilloscope Performance Measurements

3.1 Vertical section

To evaluate the performance of the vertical section of an oscilloscope, it is necessary to test the following parameters:

1. bandwidth and passband flatness;

2. probe response;

3. deflection factor accuracy;

4. transient response;

5. deflection linearity and dynamic range; and

6. single-shot response.

The test procedure for calibrating the vertical section of the oscilloscope (Appendix B) generally consists of applying well characterized waveforms to the oscilloscope and observing the responses.

Before discussing the above six parameters, special measurement considerations that affect these parameters, or the accurate determination of them, will be covered first.

3.1.1 Special measurement considerations

3.1.1.1 Limitations of measurements from the CRT face.

The CRT vertical deflection distance is usually divided into equal major divisions by horizontal graticule lines, and each major division is divided into equal minor divisions by tick marks. Typically, there are 8 major divisions with 5 minor divisions per major division. Thus, if an applied sine-wave voltage causes a peak-to-peak (p-p) deflection of 7 major divisions plus 3.5 minor divisions, the indicated p-p voltage is 7.7 X VOLTS/DIV setting, where VOLTS/DIV is the vertical deflection factor setting for the channel being used.

If sine-wave calibrator voltages are applied to an input channel, measurement of the p-p deflection has a random uncertainty due to the resolution of the measurement. If the size of a major division is approximately 1 cm or larger, the random uncertainty of a single measurement is in the order of 0.1 X VOLTS/DIV setting. The average of 5 or 6 independent measurements is often used to decrease the imprecision of a measured quantity such as p-p

deflection. The imprecision may be represented by $\pm ks$, where $\underline{s}$ is the estimated standard deviation of a single measurement. $k = t/\sqrt{N}$, where t is student's t and N is the number of measurements used to obtain the mean values [7]. If a confidence level of 0.90 is selected, k equals ~0.8 for 6 measurements and ~1 for 5 measurements.

3.1.1.2 Measurements using cursors.

Cursor circuits are used in the vertical signal channel of digital oscilloscopes to facilitate absolute and differential voltage measurements. For differential measurements, the cursors take the form of two horizontal straight lines or two "X"s, which may be positioned to measure a voltage difference. The straight lines may both extend across the CRT face, or one or both may be much shorter lines (e.g., a few millimeters). A single line or a single "X" is used to measure the voltage between the zero voltage level and the cursor position ("absolute" voltage measurement). A digital readout provides the value of the differential or absolute voltage.

The "X" positions are usually constrained to positions on the digitized waveform, and the readouts of the "X" positions are acquired from the digitized values of the stored waveform. In some instruments, very short horizontal lines may be used instead of "X"s. The generation of the long cursor lines, which are independent of waveform values, may be understood by referring to Fig. 2.2. As mentioned in section 2.2, the front panel processor (part of the μP System (7)) responds to changes in the front panel controls made by the operator. A voltage cursor is produced by holding the vertical deflection voltage constant (a single code word applied to the vertical DAC), while applying a sweep voltage to the horizontal deflection plates (a series of code words applied to the horizontal DAC). If two voltage cursors are used (delta voltage mode), the micro-processor system (7) alternately writes the position data for each cursor.

3.1.1.3 Automated readouts of waveform parameters.

The measurement of a waveform parameter is often available from an automatic readout of the parameter, or from an automatic readout of the differential voltage of cursors, appropriately placed on the waveform.

3.1.1.4 Performance of digitizer and associated digital circuits

The U.S. Army specification for which the procedures in Appendix B were written included the following significant DSO requirements:

1. Sampling rate (f_s) of at least 100 Msamples/s

2. Automatic setup for unknown repetitive input signals

3. Analog bandwidth of at least 100 MHz

4. $\geq$ 8 bits resolution (implied by accuracy requirement).

Except for single-shot response, all parameters of an oscilloscope are tested using periodic, repetitive waveforms. Equivalent-time sampling over many acquisition cycles (triggered events) is used to "acquire" a waveform, and the resulting digital data fill the scope memory (record) [8]. Depending upon the ET sampling method (e.g., sequential, random, multiple-point random), the number of samples per acquisition cycle ranges from 1 to over 1000 [9].

Built-in processing often includes signal averaging and auto setup (item 2 above) which provides for stable automatic triggering, suitable sweep speed and proper scaling. Signal averaging of the data from two or more acquired waveforms is used to decrease uncorrelated noise. The signal-to-noise ratio is improved proportionally to the square root of the number of acquisitions that are averaged [10]. (See the discussion on effective bits, following equation 5.)

A sample/hold (S/H) or track/hold circuit is often used ahead of the analog storage (CCDs, etc.) or the fast digitizer of a channel. The analog bandwidth of a channel usually refers to the bandwidth of the input circuits preceding the S/H. For real-time sampling, the usable bandwidth is usually determined by the sampling rate and reconstruction methods used (see section 3.1.2.6).

The Army specification calls for a DSO bandwidth of at least 100 MHz, using repetitive sampling. The measurement of this bandwidth is discussed in section 3.1.2.1. Assuming that the ET sampling rate is substantially higher than the Nyquist rate, this measurement yields the analog bandwidth as defined above.

Digitizer errors

Figure 3.1 shows the input voltage-output code transfer characteristic for a 3-bit digitizer, which will aid in describing digitizer errors. The terminology shown and the definitions to be given are based on the "IEEE Trial Use Standard for Digitizing Waveform Recorders" [11]. This document is also applicable to digital oscilloscopes.

The code transition levels in the figure are represented by T(1), T(2), ... T(k). T(k) is the input voltage that corresponds to the transition point between two given, adjacent codes. The transition point is defined as the input value which causes 50% of the output codes to be greater than or equal to the upper code of the transition and 50% to be less than the upper code of the transition. For example, T(1) = 1.0 unit of voltage and ideally causes codes 000 and 001 to each appear 50% of the time.

NOTATION:

T (1), T (2), . . T (k)	CODE TRANSITION LEVELS
Q	IDEAL CODE BIN WIDTH
W (k)	CODE BIN WIDTH: W (k) = T (K+1) − T (k)
∈ (k)	DIFFERENCE BETWEEN T (k) AND IDEAL T (k)

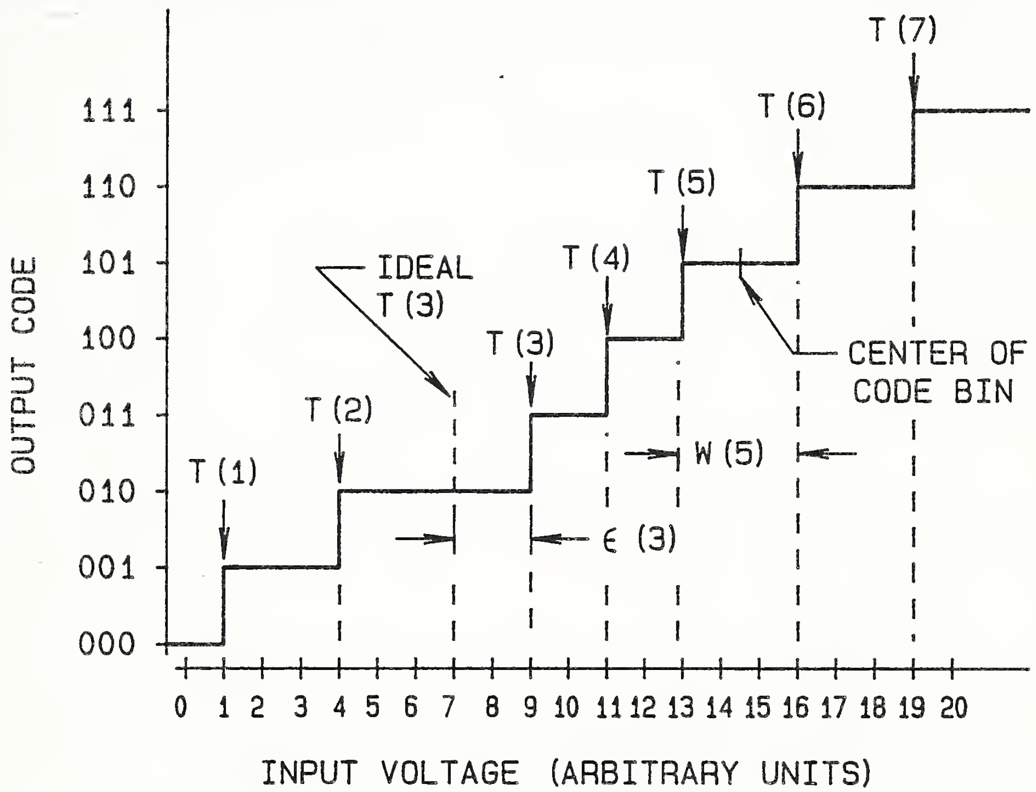

Figure 3.1. Input voltage-output code transfer characteristic of a 3-bit digitizer. Gain and offset were adjusted for zero error at zero and full-scale inputs.

Code bin width is defined as $W(k) = T(k+1)-T(k)$, where k identifies the transition level. The ideal code bin width is represented by Q (3 units in the figure). Nonlinearities result when W(k) differs from Q. Differential nonlinearity (DNL) is given by

$$DNL(k) = \frac{W(k) - Q}{Q} \quad \text{and} \tag{1}$$

$$DNL = \max\left|\frac{W(k) - Q}{Q}\right|, \tag{2}$$

where W(k) of equation (1) above refers to a specific code bin width, and equation (2) refers to the maximum differential nonlinearity in the digitizer. In the figure, $DNL(3) = (5-3)/3 = + 2/3$ LSB. Similarly, $DNL(4) = DNL(5) = (2-3)/3 = - 1/3$ LSB (least significant bit).

Integral nonlinearity (INL) is expressed by

$$INL = \frac{100 \max |\epsilon(k)|}{Q2^N} \%. \tag{3}$$

The maximum $\epsilon(k)$ is $\epsilon(3) = 2$. Therefore,

$$INL = \frac{100 \times 2}{3 \times 8} = 8.3 \% .$$

Monotonicity

A digitizer is monotonic if it has output codes that do not decrease (increase) for a uniformly increasing (decreasing) input voltage, disregarding random noise. Missing codes result when the output code changes by more than 1 least significant bit (LSB) as the input voltage passes through any particular voltage level. For example, if T(3) occurred at the same input level as T(4) (see Figure 3.1), code 011 would be missed.

With an ideal digitizer, all W(k) equal Q, and each output code corresponds to the center of a code bin. A signal falling into a code bin, which is not at the center, generates a quantization error equal to the distance of the signal from the center of the bin. The rms error over many samples can be approximated by [11].

$$E_{rms} = Q/\sqrt{12} \tag{4}$$

Aperture uncertainty (sampling time jitter) is the standard deviation of the sample instant in time. If a sample/hold (S/H) circuit is used, the sample instant in time depends on the response of the S/H circuit while it is making

the transition from the sample to the hold mode [12]. Short-term aperture uncertainty is usually measured over the time period required to fill a record. This period is short for real-time sampling, but is usually much longer for equivalent time-sampling. A record is a sequence of digital data samples stored in the acquisition memory of a digital oscilloscope. Usually a record of data fills the memory.

A digitizer may be triggered by either the signal being recorded or by an external pulse at an independent input. Trigger delay is the elapsed time between the occurrence of a trigger pulse (or the signal being used as a trigger) and the time at which the first, or a specified data sample, is recorded. Trigger jitter is the standard deviation of the trigger delay time over multiple records [11]. If there is more than one sample per triggered event, then there may be jitter between the samples which is independent of the jitter between the trigger and the samples occurring during an acquisition cycle. In that case, the total jitter of the samples is the rms sum of the trigger jitter and the jitter between samples. Jitter causes a digitizing error for dynamic signals, which is equal to the timing error times the slope of the signal recorded at that instant.

Code transition levels such as shown in Figure 3.1 are obtained using dc inputs; therefore, the transfer characteristic is the dc response of the digitizer. One measure of the dynamic response is determined by applying sinusoidal input signals with frequencies ranging from dc to $f_s/2$, where f_s is the sampling rate. The digitizer response can be obtained at higher frequencies if repetitive sampling is used.

Usually the dynamic accuracy is less than the dc accuracy. Effective bits (EB) is a figure of merit that is often used as an overall measure of dynamic performance. The following procedure is used to obtain the EB of a digitizer: Apply a low distortion sine wave to the digitizer source, and record the data. Fit a sine-wave function to the data record so that the sum of the squared differences between the data and the function is minimized. This actual rms error is then compared with the ideal quantization error (generated by an ideal digitizer) and used in the equation

$$EB = N - \log_2 \left\{ \frac{\text{rms error (actual)}}{\text{ideal quantization error}} \right\}, \quad (5)$$

where N is the number of bits of an ideal digitizer. The actual rms error includes quantization error (ideal), differential nonlinearity, integral nonlinearity, missing codes, noise, and digitizing error caused by trigger jitter and jitter between samples.

The shortcoming of the EB specification is that it does not include amplitude flatness and phase linearity information [13]. However, this information can be obtained from sampled step-response data [14].

The rms error caused by random and quantization noise and shown (indicated) in the numerator of equation 5 can be reduced by signal averaging. However, the

remaining error in the numerator, caused by differential and integral nonlinearity, missing codes and non-random jitter and noise, cannot be reduced by signal averaging. The total error from these latter five quantities is usually less than one-half the denominator of the bracketed term. Therefore, signal averaging can make the value of the bracketed term less than 1, thus making EB > N. Decreasing the quantization noise depends upon the presence of at least 1 LSB of random noise in the system. If there were no noise, each subsequent acquisition would produce the same wave form points and averaging would have no effect.

It should be noted that the EB and step response tests are usually applied to the entire input section, i.e., the input attenuator and input amplifier, as well as the digitizer.

3.1.2 Evaluation of performance

The U.S. Army specifications for a storage oscilloscope (Appendix A) call for two identical input channels, Channel 1 and Channel 2. Each channel must be tested to meet all vertical section specifications; therefore, the discussions that follow apply to both channels.

3.1.2.1 Bandwidth and Passband Flatness

The bandwidth specification requires a frequency response flat to ± 0.25 dB (± 2.84%) from dc to 50 kHz and flat to ± 0.5 db (± 5.6%) for higher frequencies, except for a permissible roll-off to -3 dB (-29.3%) at 100 MHz or higher.

A bandwidth (BW) switch is usually provided on wideband oscilloscopes to reduce interference from unwanted high-frequency signals when viewing low-frequency signals. Such a switch usually has a full bandwidth (FBW) position and one or two reduced bandwidth positions. The DSO specification calls for a selectable bandwidth reduction from FBW to 20 ± 5 MHz (-3 dB point), with a frequency response roll-off of at least 6 dB per octave. The BW switch is left in the FBW position for all of the bandwidth/flatness measurements discussed below.

The flatness of the frequency response for any given amplifier range is the oscilloscope response (gain) for all test frequencies, relative to the response at the reference frequency. In order to measure the frequency response of each range, it is necessary to apply input signals from voltage sources that have a known frequency response. Preferably, the p-p values for each range of the output from the voltage source should be 4 to 10 times flatter across the frequency passband than the corresponding scope flatness specification.

The p-p flatness of a voltage source may be specified by its manufacturer over various frequency bands, or it can be derived from an accuracy specification of its rms voltage values. In the latter case, the p-p flatness will need to be further derated from the rms accuracy specification because of possible effects of harmonics and noise. The effect of total harmonic distortion and noise (THD + n) on the uncertainty of the p-p voltage from the source can be estimated using the following considerations.

With ac voltage standards (sources), the harmonic content is usually concentrated in the second and third harmonics, with the third harmonic having a much larger effect on the p-p value. The worst case consists of THD that is composed mostly of 3rd harmonic, phased for maximum p-p value of the combined waveform. However, in practice the THD is not composed entirely of the third harmonic, and its phase change with frequency may not yield a maximum p-p change. On the other hand, the additive noise (n) is usually nonsinusoidal with a greater crest factor than a sinusoidal waveform. Usually, the noise portion of the (THD + n) specification will be considerably smaller than the THD portion, despite its greater effect on the p-p voltage. Without extensive analysis of the individual contributions of THD and n of a particular source on the p-p value, an average worst case p-p voltage uncertainty is estimated by assuming the same crest factor for both the rms accuracy and the (THD + n) error. Therefore,

$$\text{p-p voltage uncertainty } (\%) \leq \pm 2\sqrt{2}\,[\text{Accuracy} + (\text{THD} + n)], \quad (6)$$

where the Accuracy and (THD + n) are specified in percent.

The equivalent uncertainty in p-p volts (ϵ_{ca}) can then be determined for a given voltage source (calibrator) setting (converted to p-p volts), and this is the basis for the values given in Appendix B. The uncertainty values (ϵ_{ca}) may be used to obtain uncertainties for absolute determinations at a particular frequency or for flatness determinations. For the latter, the uncertainty at the reference frequency is added to the uncertainties of the levels at the other frequencies in the range of interest.

Figure 3.2 shows the voltage sources selected for the frequency response measurements. Bipolar dc voltages from a dc calibrator (±0.01% accuracy) are applied to the oscilloscope under test to obtain its dc response for a given range. The "p-p response" is obtained by adding the magnitudes of the readouts of the digitized voltage from the oscilloscope for each polarity of input voltage. The ac voltage response of the oscilloscope over the 10 Hz to 500 kHz range is measured using an ac voltage calibrator with a calculated p-p voltage uncertainty (using Eq. 6) of less than ± 0.8%. The calibrators provide p-p voltages up to 300 V.

The leveled sine wave oscillator and rf amplifier indicated in Figure 3.3 cover the frequency range from 500 kHz to 100 MHz. The oscillator is used without the amplifier for p-p voltages up to 5.5 V and with the amplifier for p-p voltages up to 60 V. For any selected amplitude between 30 mV p-p and 5.5 V p-p, the oscillator has a specified p-p voltage flatness of ± 1%, relative to its 50 kHz reference. A p-p detector and a dc DVM are used to monitor and manually control the p-p voltage from the oscillator-amplifier (Osc-Amp) combination (see Figure 3.3). For any given voltage range, the amplitude of the oscillator is adjusted to maintain a constant dc voltage from the p-p detector. The flatness of the voltage is ± 2%, relative to the voltage at 500 kHz.

The oscillator and Osc-Amp are each designated a "sine-wave generator" in Appendix B. The flatness specification for either configuration is represented by ϵ_g, where ϵ_g is the uncertainty of the sine wave generator

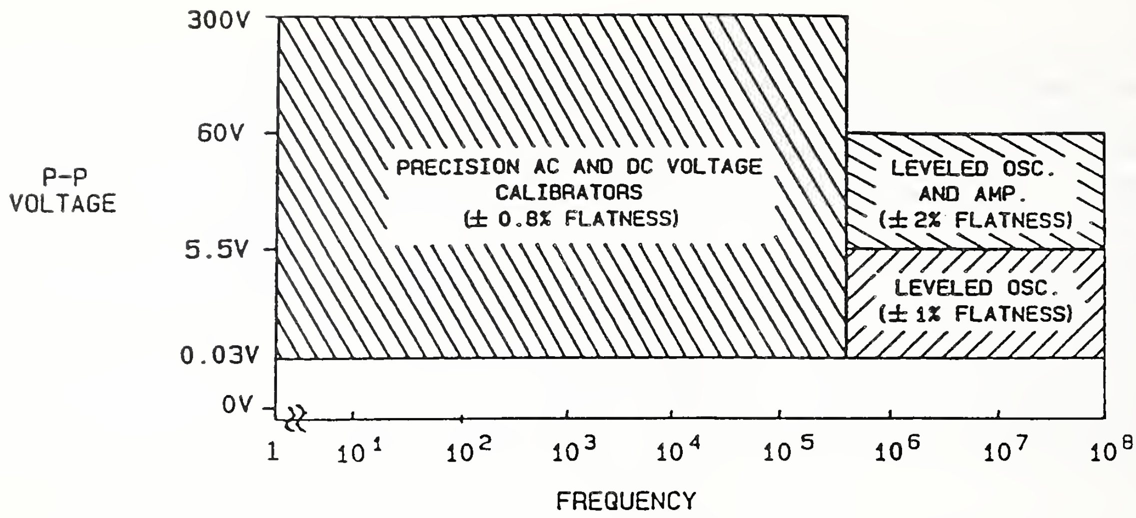

Figure 3.2. Voltage sources used to measure frequency response (flatness) of an oscilloscope under test for the frequency range of 0 to 100 MHz.

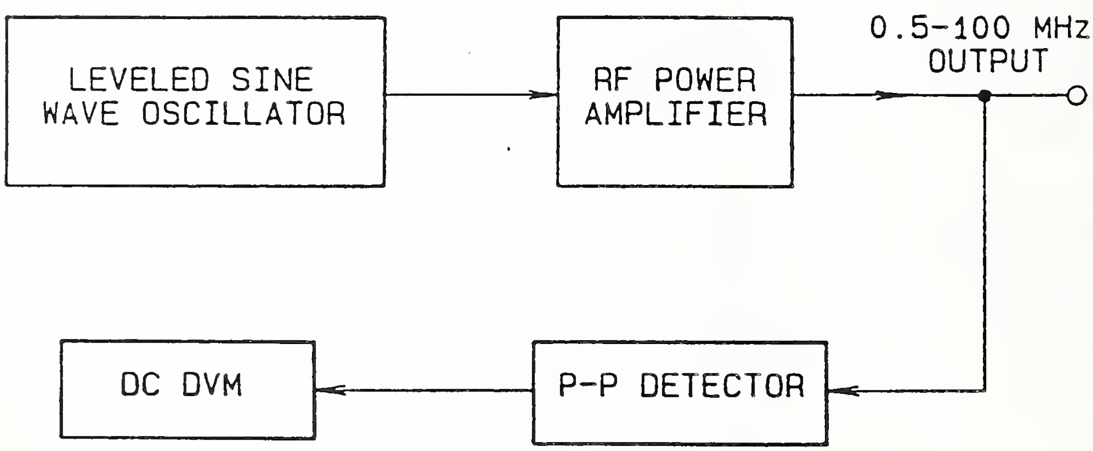

Figure 3.3. Oscilloscope-amplifier (Osc-Amp) combination used to provide p-p voltages up to 60 V for 0.5-100 MHz range. The detector is described in Appendix C.

relative to the voltage at the reference frequency (50 kHz for the oscillator, 500 kHz for the Osc-Amp).

The p-p voltage at 50 kHz serves as the reference voltage for each amplitude setting of the voltage sources. Since the Osc-Amp response is not flat below 500 kHz, 500 kHz was used as its reference frequency. The oscilloscopes to be tested generally have a slightly different response at 500 kHz than at 50 kHz. This response difference is measured using the ac calibrator and is referred to as "ΔV = flatness at 500 kHz" in the data voltage tables of Appendix B. This quantity must be added to the flatness quantities above 500 kHz, so that all oscilloscope frequency responses are relative to its response at 50 kHz.

3.1.2.2 Probe response

The bandwidth specification should be met with and without the use of 10:1 voltage divider probes. The probes supplied with the oscilloscopes will generally be of the passive type, having 10 MΩ input impedance when the oscilloscope input impedance is 1 MΩ.

The schematic shown in Figure 3.4 is representative of this type of probe [15]. For frequency-independent voltage division, C_1 is adjusted to equal $(C_2 + C_3)/9$. Since C_3 increases with cable length of the probe, the input capacitance also increases with probe length and is approximately 10.8 pF and 13.5 pF for lengths of 1.3 m and 2.0 m, respectively.

Capacitor C_1, is adjusted for zero overshoot and undershoot when a high quality square wave of approximately 1 kHz frequency is applied to the probe. If misadjusted, overshoot and undershoot result with exponential recoveries. The time constant of the exponential is in the order of 100 μs.

Figure 3.5 shows an equivalent circuit of Figure 3.4 when a ground lead (typically 6 inches long) is used in conjunction with a probe tip. The ground lead inductance L and C_{in} form a series resonant circuit with negligible damping. Therefore, ringing will occur when a pulse with small rise or fall time is applied to the probe. Also, an excessive value of L can limit the charging current to C_{in}, limiting the risetime capability of the probe. Use of a probe tip to BNC adapter decreases the inductance to a very small value and greatly reduces these problems. These adapters are part of the probe specification, and must be used when testing the performance with a probe.

To limit the capacitive input current to a safe level, it is necessary to derate the probe voltage as the input signal frequency is increased.

Typical deratings for a probe of the type represented in Figure 3.4 are shown below:

Frequency	Maximum Voltage (dc + peak ac)
DC	500 V
2 MHz	400 V
5 MHz	105 V
10 MHz	90 V
50 MHz	40 V
100 MHz	40 V

Consistent with these deratings, the test procedure in Appendix B limits probe voltage to 300 V p-p (±150 V) below 500 kHz and to 60 V p-p (±30 V) for the 1-100 MHz range.

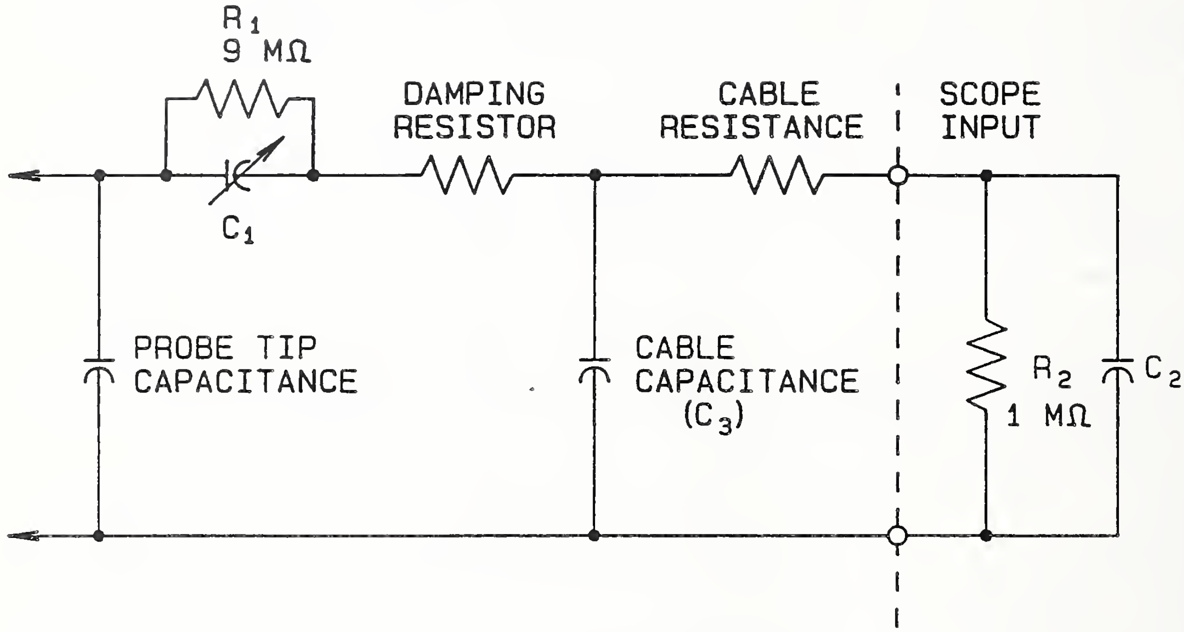

Figure 3.4. Schematic diagram of typical passive probe with 10:1 voltage division.

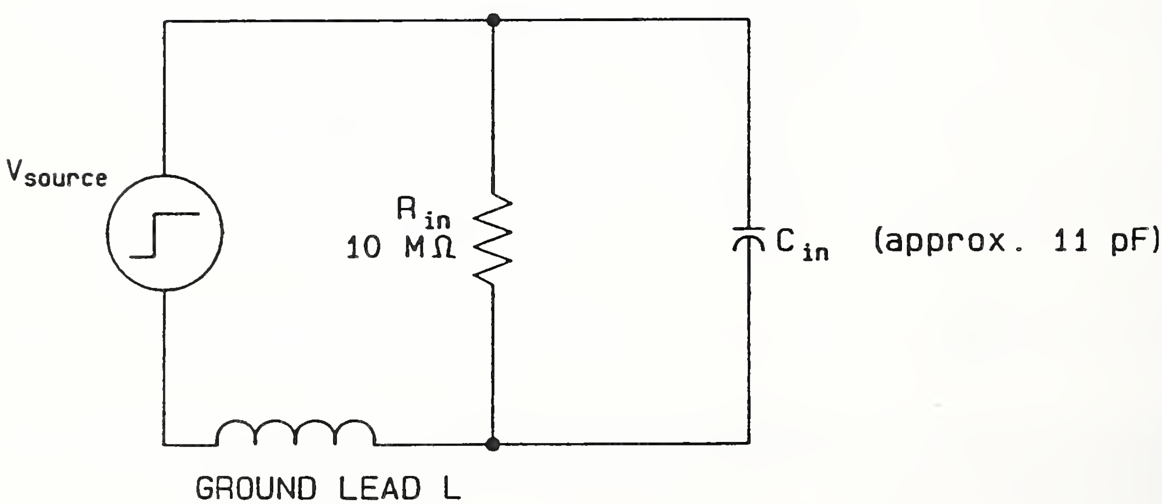

Figure 3.5. Equivalent circuit of typical passive probe when a ground lead is used with probe tip.

3.1.2.3 Deflection factor measurements

The deflection factor (volts per unit of deflection) accuracy for both vertical channels is specified as ± 2% for each range. Preferably, the measurement of the deflection factors should be made with accuracies several times better than this figure. Reference to Tables 10.3.2a-1 to 10.3.2p-1 and 10.3.2a-2 to 10.3.2p-2 of Appendix B shows that the dc calibrator has the highest accuracy of the voltage sources used for bandwidth measurements. However, thermal drifts in the test oscilloscope can cause the measurement accuracies using a dc calibrator to be poorer than when using an ac calibrator. Therefore, ac test voltages from the ac calibrator were used for these measurements. A 50 kHz test frequency was selected since this frequency was used as the reference for all (flatness) bandwidth measurements (see section 3.1.2.1).

The bandwidth measurements for each scope range consisted of comparing the deflection factors at frequencies ranging from dc to 100 MHz with the deflection factor at 50 kHz. Consequently, the deflection factors were measured at 50 kHz in making the bandwidth determinations. This measurement data is listed in Tables 10.3.2a-1 and 10.3.2a-2 of Appendix B. The measured value of the p-p voltage for each scope range is designated by V_r, the average of 6 readings. The accuracy of V_r is $\epsilon_r = \epsilon_{ca} + 0.8s$, where ϵ_{ca} is the estimated accuracy of the p-p calibrator voltage at 50 kHz, s is the estimated standard deviation of a single deflection measurement on the test scope, and the quantity 0.8s is the imprecision of V_r for a confidence level of 0.90 (see section 3.1.1.1).

The vertical deflection data from Tables 10.3.2.a-1 and 10.3.2.a-2 is also listed in Tables 10.3.4.2-1 and 10.3.4.2-2, along with the specification limits. The specification limits for each range are the estimated p-p calibrator voltages, plus or minus 2 percent.

3.1.2.4 Transient response

The transient response of an oscilloscope is characterized by its rise time (T_R) and fall time (T_F) (transition durations), overshoot and undershoot, aberrations, common mode rejection, and probe response. The probe response was discussed earlier in section 3.1.2.2.

> Note that if the vertical amplifier of the oscilloscope has a 6 db/octave roll-off at the upper band edge, the relation $BW \times T_R = 0.35$ applies, where BW and T_R are in gigahertz and nanoseconds, respectively.

Figure 3.6 illustrates some of the transient response parameters that are usually measured. The aberrations shown might be caused by capacitive coupling from the input to an attenuator output or to some succeeding stage of the input amplifier. Also, a signal applied to the other channel might be coupled to the channel in question. The overshoot (V_o) and undershoot (V_u),

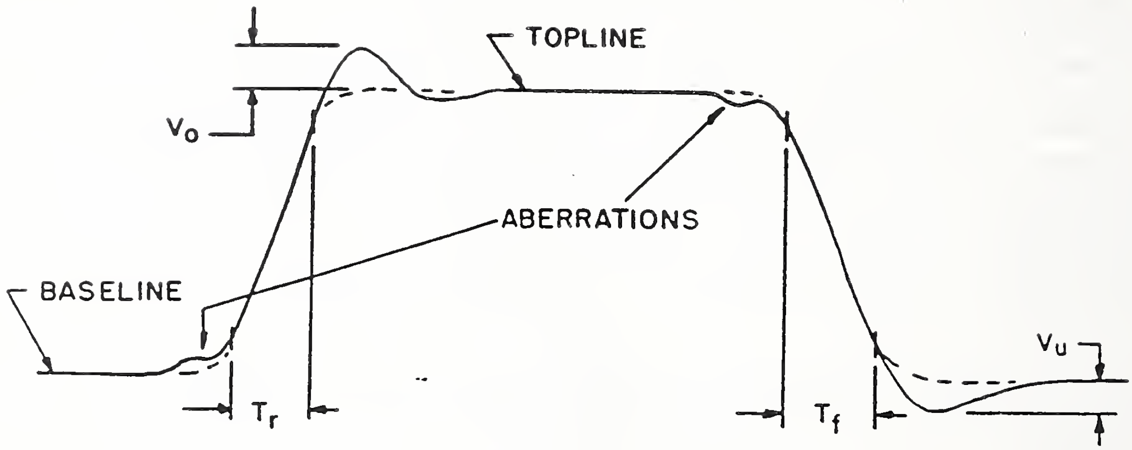

Figure 3.6. Oscilloscope response to ideal input pulse. Defects in the scope response are the overshoot (V_o), undershoot (V_u) and the aberrations.

also called aberrations, may occur if the input amplifier has a poor frequency response characteristic.

To test the transient response of a (storage) oscilloscope, an ideal pulse (flat baseline and topline and very small rise and fall times) is desirable for the input stimulus. A test pulse acceptable for testing most oscilloscopes has an overshoot, undershoot, and other aberrations less than one percent of the pulse amplitude and a rise time 8 to 10 times smaller than that of the oscilloscope. The DSO specification calls for a 3.5 ns or less rise time with and without the probes attached. The overshoot, undershoot, and any other aberrations are specified to be less than ± 4% p-p of the pulse amplitude (topline-baseline). A precision pulse generator with 0.3 ns rise time was used as the input stimulus. Its topline flatness specification included typical values of ± 0.5% each for slope and perturbations, and ± 1% for a precursor (baseline flatness).

On some DSOs, a number of the pulse parameters can be automatically measured and read out on the CRT. Alternatively, on most DSOs the delta time and delta voltage quantities can be read out after the cursors have been positioned about the parameter to be measured.

Common mode voltage may be defined as the algebraic average of two signal voltages applied to a balanced circuit, such as the inputs to a differential amplifier. Amplification of the difference between the two signals is usually desired, along with a negligible response to (rejection of) the common-mode voltage. The common mode rejection ratio (CMRR) of an oscilloscope may be

defined as the response to a sine wave applied differentially to the two oscilloscope inputs, divided by the response to the same signal applied between signal ground and the inputs tied together. The CMRR decreases with increased frequency and may vary with the selected range. Historically, high CMRRs for oscilloscopes (e.g., up to 100,000) have been provided at dc and low frequencies through the use of a special differential input preamplifier. Although the CMRR usually decreases rapidly above 100 kHz, the use of a differential preamplifier is satisfactory up to 20 MHz or higher.

Very wide-band oscilloscopes often have two single-ended channels, which inherently do not offer common mode rejection. However, if polarity inversion is selectable in at least one channel, common mode rejection can be obtained by inverting one channel and setting the channel selector to ADD. The CMRR is limited by dissimilarities between the channels, such as gain differences as a function of frequency and polarity. The Army DSO specification calls for a CMRR of at least 10 at 50 MHz. The CMRR is usually larger at lower frequencies.

When comparing fast pulses that are essentially equal in amplitude, errors caused by unequal cable terminations should be considered. (Also, identical connecting cables should be used.) A typical tolerance for 50 Ω feed-through terminations is ± 2%, although smaller tolerances are available. If the oscilloscope input impedances serve as the cable terminations, the tolerance on these impedances likewise can cause apparent lower CMRR. The Army DSO specification calls for an input impedance of 50 ohms ± 1%.

3.1.2.5 Deflection linearity and dynamic range

The differential and integral nonlinearities of digitizers were defined in section 3.1.1.4. The nonlinearity of an input amplifier is generally measured in combination with the digitizer differential and integral nonlinearities.

When mid-band frequency signal excursions are within the signal range of the digitizer, little if any distortion is expected in the amplifier. However, full-scale signals (e.g., pulses) containing upper band-edge frequency components may experience some change in overshoot or undershoot as the top line and bottom line are positioned at various locations on the oscilloscope face. Thus, the amplifier response characteristic may vary with signal level and polarity.

A measure of the high-frequency dynamic range of the amplifier can be made by positioning a symmetrical 6-8 cm (p-p) square wave (T_R and T_F less than 1 ns) as follows:

(a) with the top lines of the square wave on the bottom graticule line, and

(b) with the bottom lines of the square wave on the top graticule line.

The waveform overshoot or compression (waveform rounding) of (a) and the undershoot or compression of (b) should be measured and compared with the corresponding waveform aberration when the square wave is centered on the

scope screen. Any change in the waveform distortion indicates amplifier nonlinearity and a lack of high frequency dynamic range. The DSO specification calls for the square wave overshoot and undershoot to change no more than ± 1 percent with the above measurement.

3.1.2.6 Single-shot response

The single-shot (real-time) method of sampling was described briefly in section 2.2. In the single-shot mode, one acquisition cycle (triggered event) is used to capture an input signal. A common application of this mode of operation is to capture and store waveforms representing single physical events (transients). According to the Nyquist sampling theorem, unambiguous resolution of a signal is possible only if the sampling rate is at least twice the signal's highest frequency component [16]. However, even sampling above the Nyquist rate does not assure a good reconstruction of the displayed waveform. This is because the displayed waveform is highly dependent on the reconstruction algorithm, especially when the waveform is sparsely sampled. The simplest waveform reconstruction algorithm is linear interpolation between the dots. Linear interpolation works well when the sampling rate is well above the waveform bandwidth. At 10 samples per cycle of a sinusoidal waveform linear interpolation is accurate to within 5%. When the sampling rate is decreased to four times per cycle the accuracy decreases to approximately 30%. However, interpolation methods using digital filters such as (sin x)/x have been used to improve the reconstruction accuracy for small sampling rates of as few as 2.5 samples per cycle [17].

On the other hand, when attempting to reconstruct a sparsely sampled transition edge of a step-like waveform, some of the more efficient reconstruction techniques can cause waveform distortion. A step-like function with less than three samples taken during the transition period can cause ringing, preshooot, and overshoot depending on the reconstruction algorithm used. To minimize this effect some manufacturers provide analog filtering hardware prior to sampling.

Paragraph 10.6.1 of the Army specifications calls for the single-shot response of the DSO to be tested using pulses with a rise time of 70 ns. Since the required DSO sampling rate is 100 MHz (minimum), the test waveform will be sampled 7 times between the 10-90 % part of the leading edge on the pulse. This yields good detail of the leading edge. Also, any shock excitations in the DSO input section caused by the test pulses probably will be sufficiently low in frequency (or low in amplitude if the frequency is high) to be adequately reproduced by the sampling, even if linear interpolation is used.

3.2 Horizontal Section

As indicated in section 2.2, a DSOs time base employs an accurate clock, as opposed to an analog sweep. This results in a much higher time base accuracy for the DSO. Also, because the ADCs of a DSO can be much more accurate than an analog scope's output amplifier and CRT display, the DSO offers improved vertical accuracy. This factor enables a DSO to measure time differences with better resolution and accuracy than is possible with analog scopes.

A DSO's horizontal section performance is evaluated chiefly by the following measurements:

1. Time-base linearity and accuracy measurements

2. Jitter measurements

3. X-Y bandwidth and phase measurements

3.2.1 Special Measurement Considerations

Before describing the above measurements, the use of cursors and automatic readouts for measurements will be discussed briefly.

3.2.1.1 Time measurements using cursors

Except for employing vertical instead of horizontal cursor lines, time measurements are made in the same general way as voltage measurements (see section 3.1.1.2). However, to generate vertical cursors instead of horizontal ones, the functions of the vertical and horizontal DAC's are reversed (refer to Fig. 2.2). A vertical (time) cursor is produced by a digital code word applied to the Horizontal DAC (10), and a ramp-producing series of code words applied to the Vertical DAC (4).

3.2.1.2 Automated readout of waveform parameters involving time measurements

The discussion in section 3.1.1.3 is also applicable to the measurements of pulse width, waveform periods, and other time quantities. Quantities involving both time and voltage, such as the rise and fall times of pulses, can be read out automatically or can be calculated from differential (delta) time and voltage measurements.

3.2.2 Evaluation of Performance

3.2.2.1 Time-base linearity and accuracy

The time-base accuracy for real-time sampling is limited only by the sampling clock accuracy and is typically ± 0.01% or better. Equivalent-time measurements usually involve the use of analog circuits, such as linear ramps, to measure the time intervals between trigger and clock pulses. The measurement accuracy using these circuits is in the order of 0.1%.

A time-mark generator is usually used to measure sweep-speed accuracy and linearity for oscilloscopes. For any SEC/DIV range requiring an accuracy determination, the time mark generator should be set so that time marks coincide approximately with the vertical graticule lines. Then, the vertical (timing) cursors should be positioned on the 2nd and 9th marks from the left side. The difference between the delta time reading and the marker spacing is the nominal sweep speed error. The uncertainty of this measurement is

$$\epsilon_m = \pm [\epsilon_{ca} \pm ks], \tag{7}$$

where ϵ_{ca} is the calibrator uncertainty, and ks is the imprecision of the average of N measurements and s is the estimated standard deviation of a single measurement. k is a function of the selected confidence level and N (see section 3.1.1.1).

The horizontal linearity is measured by adjusting the sweep speed slightly so that the 1st and 11th time marks fall exactly on the 1st and 11th vertical graticule lines. Then, nonlinearity is indicated by any difference between the graticule lines and the time marks.

The above measurement procedures are applicable to both the main (A) sweep and the delayed (B) sweep.

3.2.2.2 Jitter measurements

The Army specification calls for measurements of the delayed (B) time base jitter of analog scopes. The specified maximum peak-to-peak jitter (0.005%) is in terms of the delaying (A) sweep (see section 2). This jitter is usually only evident for large delays and fast B sweeps, i.e., the SEC/DIV range is large for the A sweep and very small for the B sweep. The MIX mode or A INTEN mode should be used for this measurement. The Army specification exempts DSOs from this jitter measurement.

Sampling time jitter (aperture uncertainty) for DSOs was discussed in section 3.1.1.4. As noted there, "jitter causes a digitizing error for dynamic signals, which is equal to the time error times the slope of the signal recorded at that instant." By using an oscilloscope's ENVELOPE mode of acquisition, the oscilloscope records and displays signal minima and maxima over an operator-selected number of triggered waveforms. This display may show the amplitude jitter of the waveform. If the signal voltage variation appears to be proportional to the magnitude of the waveform slope, the voltage jitter is probably caused by time jitter. Dividing the voltage jitter by the waveform slope should give a rough estimate of the time jitter.

3.2.2.3 X-Y bandwidth and phase measurements

The display mode of the test oscilloscope is set to X-Y Display for these measurements. The Army specification calls for a Y-axis bandwidth equal to the Channel 1 bandwidth (100 MHz), and an X-axis bandwidth of at least 3 MHz.

The test procedure for the Y-axis consists of applying a sine wave from a leveled sine-wave oscillator to the Y input, and increasing the frequency until the response decreases to -3 dB of its response at the reference frequency of 50 kHz. The -3 dB frequency must exceed 100 MHz. In the case of the X-axis test, the sine wave is applied to the X input and the frequency is again increased until the response decreases to the -3 dB value. The -3 dB frequency must exceed 3 MHz. The sine-wave oscillator used for these tests has a peak-to-peak amplitude which is constant to within ± 1% of its 50 kHz reference value. These procedures are applicable to any other X-Y bandwidth specifications.

The Army specification limits the X-Y phase difference to 1 degree from dc to 1 MHz and to no more than 3 degrees from 1 MHz to 2 MHz.

The phase shift was measured by applying identical sine wave signals (300 mV p-p) to both channels, with the attenuators set to 50 mV/DIV. The resulting Lissajous figure, an ellipse, has a major axis approximately 8.5 cm long and a minor axis less than a millimeter in length. In order to make measurements more easily, the X and Y axis sensitivities are increased to 10 mV/DIV (see Figure 3.7). The quantity W is proportional to the minor axis of the ellipse and is measured in terms of minor divisions along the vertical axis. W is proportional to the phase angle and can be calibrated in terms of degrees. For the signal levels and scope sensitivity used, the phase difference is $\Phi \approx 2.3$ W degrees.

Nonlinearity from overdrive of the X or Y amplifier was not encountered in any of the oscilloscopes tested at NIST. If nonlinearity is suspected, the sensitivity of the X and Y channels should be increased in steps from 50 mV/DIV to 10 mV/DIV to see whether W increases proportionally with sensitivity.

An alternative measurement is to shift the phase to one of the inputs a measureable or calculable amount until the Lissajous figure becomes a straight line. Under this condition, the phase shift caused by the X-Y axes of the scope will be equal to the externally introduced phase shift to one of the inputs.

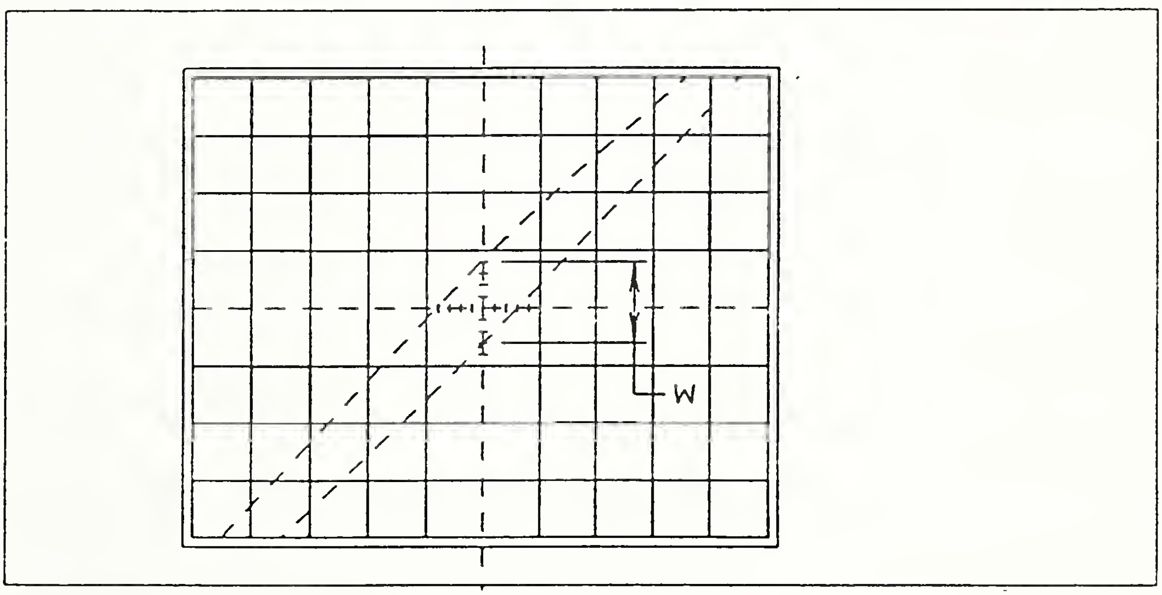

Figure 3.7 Enlarged Lissajous figure showing X-Y phase difference. W is the measure of phase difference.

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[17] Richard W. Page and Allen S. Foster, "Waveform Reconstruction Techniques for Precision Digitizing Oscilloscopes," Hewlett-Packard Journal, pp. 26-31, Feb. 1988.

APPENDIX A

PERFORMANCE SPECIFICATION FOR
THE OS-291/G STORAGE OSCILLOSCOPE

(Supplied by CECOM)

STORAGE OSCILLOSCOPE

OS-291/G

PRODUCT DESCRIPTION NUMBER

CR-PD-0241-001

DATE: 30 JUL 1987

This Specification Supersedes All
Previously Dated Specifications

U.S. ARMY COMMUNICATIONS-ELECTRONICS COMMAND
FORT MONMOUTH, NEW JERSEY 07703-5000

STORAGE OSCILLOSCOPE

Specification Summary

SCOPE: This equipment is a portable, general purpose, solid state, dual trace storage oscilloscope. It displays and measures amplitude, timing and phase relationships of complex waveforms in the frequency range of DC to 100MHz.

PERFORMANCE

Bandwidth: DC to 100MHz
Input: Two Channel, Dual Trace
Measurements: Voltage, Timing, and Phase
Waveform Storage: Digital or CRT

GENERAL
(Per MIL-T-28800C Type III, Class 3, Style D)

Temperature (operating): -10 C to 55 C
Temperature (storage): -62 C to 85 C
Size: Portable
Weight: Less than 35 pounds
Power: AC 115/230 Volts, Single Phase, 50, 60, or 400Hz

10. Performance Requirements. The equipment performance shall be over the 8 by 10 division graticule area. Unless otherwise specified, all vernier controls shall be in the calibrated position and all performance requirements shall apply with or without probes.

10.1. Warm-up. Unless otherwise specified herein, performance requirements apply to equipment after a 20 minute warm-up period.

10.2. Cathode Ray Tube (CRT). A CRT having a useful scan of at least 10 divisions wide by at least 8 divisions high shall be provided. A division shall equal at least one cm.

10.2.1. Spot Size. The trace spot size shall not exceed 0.55mm at any point on the display.

10.2.3. Internal Graticule. An illuminated internal graticule precision ruled in squares, 10 divisions wide by at least 8 divisions high, shall be furnished. The horizontal and vertical centerlines shall be ruled in 0.2 minor divisions. The 10 and 90 percent points of a 5 division or greater vertical display shall be etched across the horizontal display in readily discernible dots or marks. This graticule can be software/firmware generated in digital oscilloscopes using Raster CRT display.

10.2.4. CRT Controls. CRT controls paragraphs 10.2.4.1 through 10.2.4.5 do not apply for Raster CRT displays.

10.2.4.1. Focus. A front panel focus control shall be provided. The control circuitry shall provide sufficient resolution for a clear sharp image at all degrees of intensity below the point of beam halo.

10.2.4.2. Astigmatism. An astigmatism manual control or automatic circuitry shall be provided to control the roundness of the electron beam spot.

10.2.4.3. Intensity. A front panel intensity control shall be provided. It shall provide for optimum intensity of the displayed signal and shall provide continuous range from extinguished beam to at least greater than the point of beam halo.

10.2.4.3.1. Intensity (beam current limit). An automatic intensity limit shall be provided which limits beam current under all applications to a level which will not damage the CRT. Response time shall insure viewing of low duty cycle fast risetime pulses.

10.2.4.4. Trace Rotation. A control of recessed common screwdriver type shall be provided to rotate the trace about the horizontal axis. Rotation range shall be adequate to align the trace to the horizontal graticule lines. Sufficient offset shall be introduced to compensate for variations in the earth's magnetic field with at least +/-2 degrees overcompensation.

10.2.4.5. Graticule Illumination. A front panel control shall be provided. It shall provide variable graticule illumination from zero to greater than optimum illumination.

10.2.5. Auto-Setup/Auto-Scale. A front panel control shall be provided which when activated provides an initial setup and displays a stable, automatically triggered display for an unknown repetitive signal at an input channel. All basic settings for vertical deflection, horizontal deflection, and triggering shall automatically be made.

10.2.6. Delta Time and Delta Voltage Measurements. Cursor facilities with CRT readout shall be provided for both time and amplitude measurements. When activated, two independent, movable cursors will be superimposed across the CRT display. The alphanumeric CRT readout will display the equivalent voltage or time represented by the separation between the two cursors. Readout will account for any probe attenuation. Movability of the cursors is not required for analog storage oscilloscopes when in the storage mode.

10.2.6.1. Delta Time and Delta Voltage Accuracy.

a. +/-2 percent of full scale; for delta time intervals measured with the cursors vertically positioned anywhere on the graticule.

b. +/-2 percent of full scale; for delta voltage intervals measured with the cursors horizontally positioned anywhere on the graticule.

10.2.6.2. Alphanumeric CRT Readouts. All readout and cursor displays on the CRT shall be clear and stable to the eye for any input signal and setting combinations.

10.2.6.2.1. Display Readout Jitter. The jitter of any alphanumeric character shall not be greater than 0.10 minor divisions.

10.2.6.2.2. Numeric and Uppercase Letters. Minimum height shall be 1.5 minor divisions.

10.2.6.2.3. Lowercase Letters and Mathematical Symbols. Minimum height shall be 1.0 minor division.

10.2.6.3. Vertical and Horizontal Readout. A readout of the vertical and horizontal scale or scale factors shall be displayed on the CRT.

10.3. Vertical Section

10.3.1. Vertical Input Channels. Two channels with identical performance characteristics shall be provided.

10.3.2. Bandwidth. The -3dB bandwidth of each vertical channel shall be from DC to at least 100 MHz with and without the probes attached and at all attenuator settings. Aberrations/flatness across the bandwidth shall not be greater than +/-0.5dB.

10.3.2.1. DC Coupled Bandwidth. The response shall be no more than 3 dB down at 100 MHz and shall be within +/- 0.25 dB from DC to 50KHz.

10.3.2.2. AC Coupled Bandwidth. The response shall be no more than 3dB down at 10Hz and at 100MHz.

10.3.3. Transient Response (Overshoot and Undershoot). The transient response aberrations of each vertical channel shall be within 4 percent p-p for a 6 division step input pulse with a rise time not greater than 0.3 nsec.

10.3.4. Deflection Factors. The minimum range for calibrated vertical channel deflection factors of each channel shall be from 5 millivolts per division or less to 5 volts per division or more for both AC and DC coupling. Ranging shall be in a 5-2-1 sequence.

10.3.4.1. Uncalibrated Vertical Vernier. The deflection factor shall be continuously variable between all ranges and extend the maximum deflection factor to at least 12 volts per division. This is not required for digital oscilloscopes.

10.3.4.2. Vertical Deflection Factor Accuracy. The vertical deflection factor accuracy of each vertical channel and each vertical deflection factor range setting shall be within:

a. +/- 2 percent of full scale, at any temperature between 0 degrees C and 40 degrees C without probe.

b. +/- 3 percent of full scale at any temperature between 40 degrees C and 55 degrees C without probe.

10.3.4.3. Overload Protection. The equipment shall be capable of withstanding, for a minimum time of five minutes, at any vertical range setting without damage and the vertical channels AC or DC coupled up to:

a. 400V (DC + Peak AC), 800V P-P AC at 10K Hz or less, for 1 M ohms input impedance.

b. 5V rms, for 50 ohms input impedance.

10.3.5. Input Impedance. The input impedance at all sensitivity settings of each vertical channel shall be 1 megaohm +/- 1.5% shunted by no more than 20pF. Switchable input impedance to 50 ohms +/-1% shall be provided.

10.3.6. Vertical Channel Risetime. The risetime of each vertical input channel shall not exceed 3.5 nanoseconds with and without the probes attached when measured between the 10 and 90 percent points of a step response that is at least 6 cm high at 5mV/div.

10.3.7. Channel Separation(Isolation). The separation between the vertical input channels with both attenuators on the most sensitive range shall be not less than 50:1 at 100MHz.

10.3.8. Common Mode Rejection Ratio (CMRR). The CMRR referenced to a 6 cm amplitude sine wave with both attenuators on the same calibrated range shall be not less than 10:1 at 50MHz.

10.3.9. Direct Current Drift. The CRT trace drift of each vertical channel at the 10 mV per division setting shall not exceed 0.1 cm per hour at all input impedance settings.

10.3.10. Delay Circuitry or Equivalent. The equipment shall be capable of displaying the entire leading edge of an internally triggered 0.7 nsec or faster risetime 10 MHz square wave of one cm amplitude at 5mV per division.

10.3.11. Dynamic Range. Overshoot and undershoot of each vertical channel shall not exceed those measured at center screen by more than 1.0 percent when:

a. The top of 2 cycles of a 6 cm displayed symmetrical square wave is positioned on the bottom graticule line.

b. The bottom of the same 6 cm displayed symmetrical square wave is positioned on the top graticule line.

10.3.12. X-Y Display. The equipment shall have an x-y display capability through the vertical input channels.

10.3.12.1. X-Y Display Bandwidth. The Y axis bandwidth shall be the same as Channel A. The X axis -3 dB bandwidth shall be at least 3 MHz.

10.3.12.2. X-Y Display Phase Difference. Phase difference in the x-y display mode shall not be greater than 1 degree from DC to 1 MHz and increasing to no more than 3 degrees from 1 MHz to 2 MHz with both attenuators calibrated and in the 10mV per division positions.

10.3.12.3. X-Y Display Range. The x-y display capability shall be over the full range of the vertical attenuators.

10.3.13. Vertical Position and/or Equivalent Offset Capability. The equipment shall provide a vertical position control/capability for each channel which provide a ground position range +/- 10 divisions.

10.3.13.1. Coupling. Coupling controls for each vertical channel shall be provided. The coupling controls shall have an AC, DC and a ground position. When in the ground position, the input signal circuit shall be open and the input circuit to the input amplifier shall be grounded.

10.3.14. Display Mode. Mode selector controls(s) shall provide the capabilities of a through e below:

a. Channel A only

b. Channel B only

c. Both Channel A and Channel B are displayed (equivalent to alternate and chop)

d. Algebraic. This mode shall display the instantaneous algebraic sum of Channel A and B.

e. X-Y Display. This mode shall permit operation of the vertical channels in an X-Y display mode.

10.3.15. Polarity Inverter. A control shall be provided to invert the waveform being processed through at least one of the channels.

10.3.16. Direct Current Balance. A front panel or operator accessible DC balance control shall not be provided. The vertical channels shall be capable of retaining the DC balance within +/- 0.5 minor divisions over the attenuator range without external operator adjustment.

10.3.17. Vertical Channel Uncalibrated Vernier Indicator. An indicator lamp or readout shall be provided for each vertical channel to indicate when the vertical channel uncalibrated vernier control is not in the calibrated position. This is not required for digital oscilloscopes.

10.3.18. Vertical Channel Input Connector. Each vertical channel shall be provided with a front panel female BNC input connector.

10.3.19. Bandwidth Limiting. A control shall be provided to limit the vertical response at the -3 dB point of both channels to 20 +/- 5 MHz. This capability shall eliminate high frequency interference without affecting normal low frequency performance of the equipment. Frequency response shall roll-off at a minimum of 6 dB per octave.

10.4. Horizontal Section

10.4.1. Sweep Trigger Mode. The sweep trigger shall be selectable from any of the following trigger mode capabilities:

a. Normal. The sweep shall be selectably triggered by an internal vertical amplifier signal, external signal, or internal power line signal. A bright baseline shall be provided only in presence of trigger signal.

b. Automatic. A bright baseline shall be displayed at the maximum repetition rate for the range selected in the absence of input signals. Triggering shall be the same as in normal mode above 40 Hz.

c. Single (Main Time Base Only). The sweep shall occur once with the same triggering as normal. A capability to rearm the sweep and illuminate a reset lamp shall be provided. The sweep shall activate when the next trigger is applied after rearming.

10.4.2. Trigger Level and Slope. Controls shall be provided to permit triggering as specified below.

a. Internal. The internal trigger level and slope shall permit triggering at any point within the trigger sensitivity level (section 10.4.4) on the positive or negative slope of a full screen displayed waveform.

b. External. The external level and slope permit continuously variable triggering from at least +0.5 volt to -0.5 volt on either slope of the trigger signal.

10.4.3. Trigger Source. The trigger source shall be selectable from the following:

a. Channel A. All displays shall be triggered by the Channel A signal.

b. Channel B. All displays shall be triggered by the Channel B signal.

c. External

10.4.4. Trigger Sensitivity.

a. Internal. A stable sweep shall be obtained from a sine wave having at least 0.5 divisions p-p vertical deflection from DC to at least 50 MHz, increasing to 1.5 divisions p-p vertical deflection at 100 MHz.

b. External. A stable sweep shall be obtained from a sine wave less than or equal to 50 mV p-p vertical deflection from DC to 50 MHz, increasing to less than or equal to 250 mV p-p vertical deflection at 100 MHz.

10.4.5. External Trigger Input.

a. Input impedance. The external trigger input impedance shall be 1 megaohm +/-15 percent paralleled by not more than 22pf.

b. Maximum input. The external trigger input shall withstand, without damage, at least +/-100 volts (DC + peak AC).

c. Coupling. DC coupling capability shall be provided.

10.4.6. External Trigger Input Connector. A front panel female BNC input connector shall be provided.

10.4.7. Trigger Coupling. Controls shall be provided for the following types of trigger couplings:

a. Direct Current (DC). This type of coupling shall be provided for coupling signals from DC to 100 MHz.

b. Alternating Current (AC). This type of coupling shall incorporate a high pass filter which attenuates signals less than 30 Hz.

c. Low Frequency Rejection. This type of coupling shall incorporate a high pass filter which attenuates signals less than 15 KHz (main time base only).

d. High Frequency Rejection. This type of coupling shall incorporate a low pass filter which attenuates signals greater than 50 KHz (main time base only).

10.4.8. Trigger Jitter. Trigger jitter shall not exceed 50 psec at 100 MHz.

10.4.9. Trigger Hold-off. A trigger hold-off control shall be provided to permit the sweep period to be continuously variable to at least 10.0 times the time per division of each horizontal range from 20 msec per division through 10 nsec per division. This is not required for digital oscilloscopes.

10.4.10. Time Base (Main). The time base shall provide calibrated sweep times in a 5-2-1 sequence from 5 nsec or less/division to 0.5 seconds or more/division. A control shall be provided to select the calibrated sweep times of the main time base.

10.4.10.1. Time Base Accuracy. The calibrated sweep time shall be +/-2 percent of the setting.

10.4.10.2. Time Base Uncalibrated Sweep Vernier. The capability to provide uncalibrated sweep times in calibrated steps and up to 1.5 seconds per division shall be provided. This is not required for digital oscilloscopes.

10.4.11. Horizontal Linearity. With one time mark per division displayed and the first and eleventh marks exactly on the first and eleventh vertical graticule lines, the marks in between shall coincide with their respective graticule lines to within +/- 0.25 minor divisions.

10.4.12. Delayed Time Base Capability or Equivalent Function. A delayed time base or equivalent capability shall be provided, with calibrated variable sweep times from 10nsec/div or less to 50msec/div or more in at least a 5-2-1 sequence. This capability can be provided via the use of movable cursors, markers, or intensified zones to identify any portion of the waveform from the main sweep to be expanded.

10.4.12.1. Delayed Time Base Accuracy. The delayed time base (or equivalent) accuracy shall be +/-2 percent of the setting.

10.4.12.2. Delayed Time Base (or Equivalent) Horizontal Linearity. Same as specified in Horizontal Linearity, Section 10.4.11.

10.4.12.3. Delayed Time Base Jitter. Jitter shall be not greater than 1 part in 20,000 (0.005 percent) of the main time per division setting. This is not applicable for digital oscilloscopes.

10.4.13. Trace Intensification or Markings. The capability shall be provided to intensify or designate via cursors, the portion of the main time base which is to expand to full screen in the delayed time base.

10.4.14. Horizontal Position Drift. The CRT horizontal position drift shall not exceed 0.1 division per hour at any temperature between 0 degrees C and 55 degrees C.

10.4.15. Time Base Mode. The equipment shall be capable of providing the following time base modes:

a. Normal Sweep. This mode shall permit operation in the normal undelayed manner.

b. Delayed Sweep or Equivalent. This mode shall permit the generation of a sweep after a defined interval of delay following the trigger pulse. This shall provide the ability to display the main sweep and the delayed sweep simultaneously on the display.

10.4.16. Main Time Base Uncalibrated Sweep Vernier Indicator. An indicator shall be provided to indicate when the main time base vernier is not in the calibrated position. This is not required for digital oscilloscopes.

10.4.17. Variable Sweep Delay Time. A 20 nsec or less to 0.5 seconds or more delay time control or equivalent shall be provided.

10.4.18. Horizontal Position. A horizontal position control shall be provided to move the left hand end of the trace to the right past the center graticule line and the right hand end of the trace to the left past the center graticule line. This is not required for digital oscilloscopes.

10.4.19. Reset Single Sweep Operation. A reset feature shall be provided to arm the sweep and provide an indicator when the oscilloscope is the armed and in the single shot operation mode.

10.5. Controls Location. All operator controls and indicators shall be provided on the front panel.

10.6. Waveform Storage. The equipment shall be capable of capturing and storing a displayed waveform for a minimum viewing time of 15 minutes.

10.6.1. Single Shot Response. Equipment shall be capable of displaying and storing an 8 division high single shot input pulse rise time of 70nsec. Accuracy shall be within +/- 2% of full scale amplitude and +/- 1.4nsec.

10.6.2. Sampling Rate. If digital storage is used, then the equipment shall be capable of sampling at a rate of 100 meagasamples per second or more, on both channels simultaneously.

10.7. Calibrator. A square wave calibrator signal shall be provided through a connector mounted on the front panel. The connector shall be compatible with a probe tip supplied. The calibrator shall be short circuit proof.

10.8. Digital Interface. An IEEE standard 488-1978 interface capability shall be provided. This interface shall provide talk and listen for all oscilloscope functions required by this specification with the exception of line power on/off. This interface shall be furnished with address selections from 00 to 30 and interface functions SH1, AH1, T5, L3, SR1, RL1 or RL2, DC1, DTO, PPO, and CO implemented, shall be provided. The equipment shall be capable of transmitting waveform data through the IEEE interface (waveform dump). Waveform data transmission is not required for analog oscilloscopes while in the single shot mode. However, it is required for all modes in digital oscilloscopes and analog

APPENDIX B

TEST PROCEDURES FOR

THE OS-291/G STORAGE OSCILLOSCOPE

<u>Note:</u>

The procedures described in this document are valid only if used with test equipment that is maintained within the normal Army calibration procedures. Certain commercial equipment is identified in this document. This identification does not imply endorsement by the National Institute of Standards and Technology nor does it imply that the equipment identified is necessarily the best available for the purpose. Also, each specification description included with these procedures (in italics) have been copied with minor modifications from the specification paragraphs in Appendix A.

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NOTES

The following notes are to apprise the user of this document of some of the assumptions made in the preparation of the test procedures for a storage oscilloscope.

1. The accuracy statements of the storage oscilloscope is specified to be applicable for operating temperatures of -10° to 55°C. The warm-up times required prior to the performance of a test is given in paragraph 10.1. In this set of test procedures, all tests were designed to be conducted at a temperature and humidity level typically maintained in a laboratory environment. It is possible to conduct these tests over the specified temperature and humidity range with the addition of an appropriate environmental chamber.

2. Not all specifications contain a statement of accuracy. In such cases, the accept and reject criteria are based on an observation (such as the presence or absence of a control or display) rather than measurement data. Many test procedures contain demonstrations of the capability of the control or display but do not attempt to quantify its accuracy or performance.

3. Unless otherwise stated, all electrical performance tests will be performed to determine the performance of the oscilloscope at the front-panel connectors. For those tests that require the use of a 10:1 voltage divider probe, test probes conforming to the requirements of section 6.6.1 and provided with the storage oscilloscope by the manufacturer will be used. If no leads are provided, a Tektronix type P6053B (P/N 010-6053-11) will be used.

4. The preliminary settings of the instrument controls should be as follows when starting the performance tests:

Power Controls	
POWER	On
CRT Controls	
INTENSITY	Midrange - or automatic trace not to be intensified
FOCUS	Midrange - or automatic
SCALE ILLUMINATION	Midrange - or automatic
ASTIGMATISM	To produce a round beam spot
BEAM FIND (if provided)	Off
MENU/HELP SELECTION	Off
TRACE ROTATION	Set such that free-running trace aligns with center horizontal graticule line
VARIABLE PERSISTENCE (if provided)	Set to shortest time possible
CURSORS	On - located at bottom of screen

Vertical Controls (both channels)

VOLTS/DIV	1 V
IMPEDANCE	1 MΩ || 15pF
VARIABLE VERNIER	Off - at calibrated position
POSITION	To center trace vertically on screen
COUPLING	DC
MODE	To display Channel 1
INVERT (if provided)	Off
BANDWIDTH (if provided)	Full - 100 MHz
CURSORS	On - located at left side of screen
DC OFFSET	Off - set to zero

Triggering Controls (both time bases)

LEVEL	0.0 volts
SLOPE	Positive (+)
COUPLING	DC
SOURCE	Vertical Channel 1
TRIGGER MODE	Automatic
TRIGGER VIEW (if provided)	Off

Sweep Controls

HORIZONTAL DISPLAY	A Sweep
DELAY TIME	Set for zero time delay (or as near to zero as possible).
A TIME/DIVISION	1 ms
B TIME/DIVISION	1 ms
VARIABLE VERNIER	Off - at calibrated position
10X MAGNIFIER	Off
POSITION	To set start of sweep line at first vertical mark on graticule.
TRIGGER HOLDOFF	Set for zero holdoff (or as near to zero as possible).
CLOCK - INT/EXT	Internal clock

Digital

IEEE-488 INTERFACE	Set off - not talking, listening, or controlling
WORD RECOGNIZER (if provided)	Set off - will not inhibit triggering
MEASURE, CALCULATE, ACQUIRE WAVEFORM and such	Set off - will not apply user-defined algorithms to displayed waveform

5. The test procedures reflect the specifications defined in the document entitled "Storage Oscilloscope - OS-291/G - Product Description Number CR-PD-0241-001, received from the U.S. Army Communications Electronic Command (CECOM), dated 30 July 1987. The specifications have been reprinted exactly as presented in this document and are reproduced in italics.

6. Editorial, technical clarifications, and additions to the specifications have been indicated by enclosures in brackets [].

7. It is not always possible to test all features, ranges, and accessories that are specified by the U.S. Army Communications Electronic Command for instruments. Generally, tests are designed to cover as many of the features and as broad a range as economically feasible with commercial test equipment. It is generally not cost-effective to buy non-standard test equipment to verify the performance of specifications especially if the test equipment would be of a highly specialized nature.

8. Commercial test equipment used to verify the performance of the storage oscilloscope is assumed to perform to the manufacturer's published specification and should be fully calibrated and warmed-up prior to use.

9. Some specifications are marked as "... not applicable to digital oscilloscopes." It was deemed by the Army that a "digital oscilloscope," for the purpose of deciding applicability of a specification, is one which contains in the nomenclature on the nameplate the word "digital."

10. The nomenclature of the controls, input connectors, and other features identified in the test procedure are not necessarily the same as the names given in the Product Description. In addition, the names used in the Product Description and the test procedure may not necessarily be the same as marked on any particular oscilloscope. The two vertical channels are called Channel A and Channel B in the Product Description, however, these names have been designated in the test procedures as Channel 1 and Channel 2, respectively since this is the custom by oscilloscope manufacturers.

11. Many of the test procedures involve observation of the oscilloscope display and the subsequent evaluation of the display. Since the ability to view a display depends on room lighting, the following illumination conditions will be used when performing these procedures.

12. The oscilloscope under test may be provided with several ways to display the voltage and time parameters of a waveform under observation. The specification require that the unit provide movable cursors that may be set to provide for delta time and delta voltage measurements [1]. In addition, some oscilloscopes may provide digital displays which contain the delta time and delta voltage information. In this set of test procedures, the values obtained from such digital displays will be used to report voltage and time values, if such displays are available. If digital displays are not available, then the cursor position will be used to report the voltage and time values. In no event will the position of the waveform be estimated from the graticule engraved on the screen.

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[1]. See paragraph 10.2.6 - Delta Time and Delta Voltage Measurements.

13. The storage oscilloscope may be provided with numerous features that "enhance" the accuracy of the measurements made by the unit. For example, some oscilloscopes provide for a time axis that is "longer" than the 10 divisions specified by the Product Description document issued by the Army. Other storage oscilloscopes may provide "averaged" waveforms to reduce noise. Neither of these features are specified to be present in the storage oscilloscope under test. In general, the guidance followed in the development of the test procedures may be stated as follows: If an operational feature is specified in the Product Description, it will be used in the measurement test procedure, (unless the specification for that measurement explicitly excludes its use). Conversely, no operational feature will be used to enhance the measurement accuracy (such as signal averaging or a "scrolling" time axis display) unless that feature is specified to be present by the Product Description document. The intent of this restriction is to permit the comparison of the accuracy of various storage oscilloscopes, employing diverse technologies, in a like manner.

10.1 Warm-up

Specification:

Unless otherwise specified herein, performance requirements apply to equipment after a 20 minute warm-up period.

10.2 Cathode Ray Tube (CRT)

Specification:

A CRT having a useful scan of at least 10 divisions wide by at least 8 divisions high shall be provided. A division shall equal at least one centimeter.

Equipment:

Items	Model
Precision Optical Comparator (15X)	Bishop Model 3561 or equivalent

Procedure:

1. Count the number of major horizontal divisions displayed on the cathode ray tube. Record the number of divisions in table 10.2a.

2. Count the number of major vertical divisions displayed on the cathode ray tube. Record the number of divisions in table 10.2a.

3. With the aid of the precision optical comparator, measure the distance between each vertical line denoting a major horizontal division. Record the readings in table 10.2a.

4. With the aid of the precision optical comparator, measure the distance between each horizontal line denoting a major vertical division. Record the readings in table 10.2b.

Table 10.2a Cathode Ray Tube (CRT)- Horizontal

Measurement Description	Measurement Data	Estimated Measurement Uncertainty	Specification Limits Min.	Max.	Units
Number of horiz. div	________	N/A	10		units
Number of vertical div	________	N/A	8		units
Length of 1st horiz. div	________	±0.01	1		cm
Length of 2nd horiz. div	________	±0.01	1		cm
Length of 3rd horiz. div	________	±0.01	1		cm
Length of 4th horiz. div	________	±0.01	1		cm
Length of 5th horiz. div	________	±0.01	1		cm
Length of 6th horiz. div	________	±0.01	1		cm
Length of 7th horiz. div	________	±0.01	1		cm
Length of 8th horiz. div	________	±0.01	1		cm
Length of 9th horiz. div	________	±0.01	1		cm
Length of 10th horiz. div	________	±0.01	1		cm
	________				

Table 10.2b Cathode Ray Tube (CRT) - Vertical

Measurement Description	Measurement Data	Estimated Measurement Uncertainty	Specification Limits Min.	Max.	Units
Length of 1st vertical div	______	±0.01	1		cm
Length of 2nd vertical div	______	±0.01	1		cm
Length of 3rd vertical div	______	±0.01	1		cm
Length of 4th vertical div	______	±0.01	1		cm
Length of 5th vertical div	______	±0.01	1		cm
Length of 6th vertical div	______	±0.01	1		cm
Length of 7th vertical div	______	±0.01	1		cm
Length of 8th vertical div	______	±0.01	1		cm

10.2 Cathode Ray Tube (CRT)

10.2.1 Spot Size

Specification:

The trace spot size shall not exceed 0.55 mm at any point on the display.

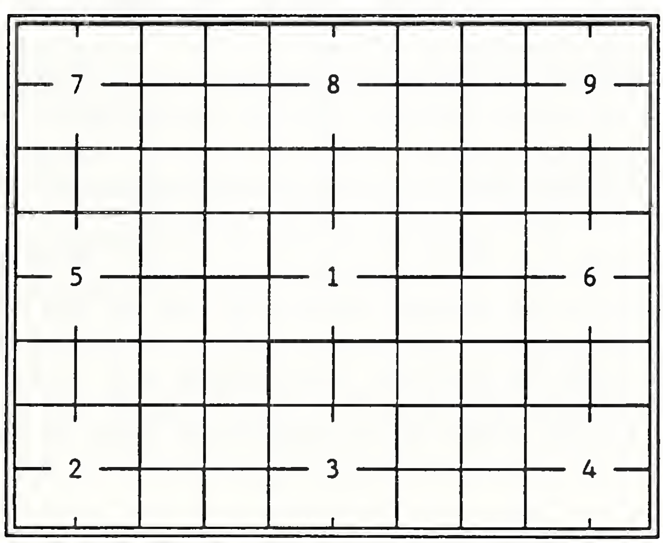
Equipment:

Items	Model
Precision Optical Comparator (15X)	Bishop Model 3561 or equivalent

Procedure:

1. Place the oscilloscope in the X-Y display mode. Do not connect any cables to the inputs of the oscilloscope. There should be a single spot on the screen of the oscilloscope. Focus the beam until the spot attains minimum size. Adjust the intensity for normal viewing.

2. Set the vertical and horizontal position controls such that the spot is in the center of the screen at position 1 on the figure below. Use the precision optical comparator to measure the size of the spot. Record the size of the spot in table 10.2.1.



The grid represents the graticule.

Spot size measurements are to be made at the numbered locations.

Figure 10.2.1 Locations for measurement of spot size

3. Set the vertical and horizontal position controls such that the spot is located at each of the next eight positions in the figure above. Use the precision optical comparator to measure the size of the spot at each of the positions and record the size of the spot in table 10.2.1.

Table 10.2.1 Spot Size

Measurement Description	Measurement Data	Estimated Measurement Uncertainty	Specification Limits Min.	Max.	Units
Spot size at location 1	________	±0.1		0.55	mm
Spot size at location 2	________	±0.1		0.55	mm
Spot size at location 3	________	±0.1		0.55	mm
Spot size at location 4	________	±0.1		0.55	mm
Spot size at location 5	________	±0.1		0.55	mm
Spot size at location 6	________	±0.1		0.55	mm
Spot size at location 7	________	±0.1		0.55	mm
Spot size at location 8	________	±0.1		0.55	mm
Spot size at location 9	________	±0.1		0.55	mm

10.2 Cathode Ray Tube (CRT)

10.2.3 Internal Graticule

Specification:

An illuminated internal graticule precision ruled in squares, 10 divisions wide by at least 8 divisions high, shall be furnished. The horizontal and vertical centerlines shall be ruled in 0.2 minor divisions. The 10 and 90 percent points of a 5 division or greater vertical display shall be etched across the horizontal display in readily discernible dots or marks. This graticule can be software/firmware generated in digital oscilloscopes using raster CRT display.

Equipment:

Items	Model
Precision Optical Comparator (15X)	Bishop Model 3561 or equivalent

Procedure:

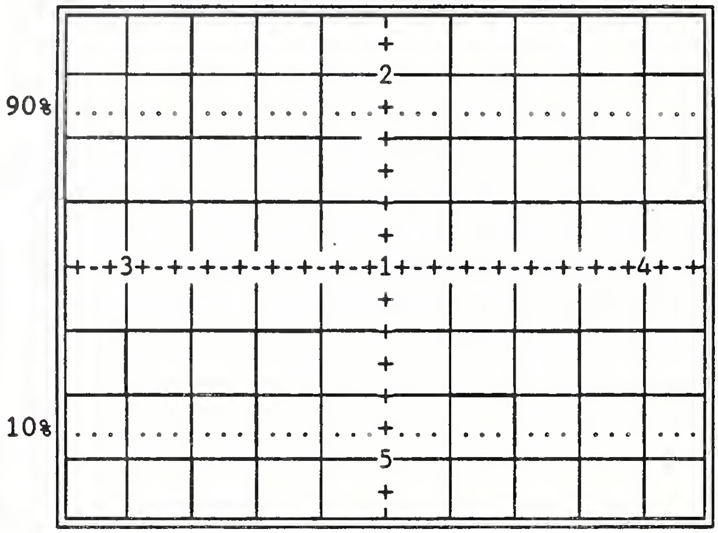
1. Assure that the graticule may be illuminated. Record the compliance (or lack of compliance) of this specification in table 10.2.3.

2. Assure that the graticule is ruled in squares, 10 divisions wide by at least eight divisions high. Record the compliance (or lack of compliance) of this specification in table 10.2.3.

3. Assure that the horizontal and vertical centerlines are ruled on 0.2 cm per major division. The approximate location of the horizontal and vertical centerlines is shown in the figure below. Record the compliance (or lack of compliance) of this specification in table 10.2.3.

4. Measure the distance between two minor divisions at the five points designated on the figure below. Record the distance between the markings of the minor divisions in table 10.2.3.

5. Assure that the 10 and 90 percent points of a 5-division or greater vertical display are etched across the display in readily discernible dots or marks. The approximate location of the 10 and 90 percent points is shown in the figure below. Record the compliance (or lack of compliance) of this specification in table 10.2.3.



The grid represents the graticule.

Assure that the 10 and 90 percent points are located approximately as shown.

Figure 10.2.3 Location for measurement of the internal graticule

Table 10.2.3 Internal Graticule

Measurement Description	Measurement Data	Estimated Measurement Uncertainty	Specification Limits Min.	Max.	Units
Is the graticule illum?	____________	N/A	Yes		
Graticule ruled in sqs?	____________	N/A	Yes		
Minor div'ns on graticule?	____________	N/A	Yes		
Minor div at point 1	____________	±0.01			cm
Minor div at point 2	____________	±0.01			cm
Minor div at point 3	____________	±0.01			cm
Minor div at point 4	____________	±0.01			cm
Minor div at point 5	____________	±0.01			cm
10- and 90% pts. marked?	____________	N/A	Yes		

10.2 Cathode Ray Tube (CRT)

10.2.4 CRT Controls

CRT controls paragraphs 10.2.4.1 through 10.2.4.5 do not apply for raster CRT displays.

10.2.4.1 Focus

Specification:

A front panel focus control shall be provided. The control circuitry shall provide sufficient resolution for a clear sharp image at all degrees of intensity below the point of beam halo.

Equipment:

Items	Model
Manufacturer's Instruction Manual	Supplied by Manufacturer
Sine-Wave Generator	Tektronix SG 503 or equivalent

Procedure:

1. Assure that a front-panel focus control has been provided. Record the compliance (or lack of compliance) of this specification in table 10.2.4.1.

2. Read the instruction manual supplied with the instrument to determine the existence of control circuits that provide for a clear sharp image at all degrees of intensity. Record the existence of the presence of such circuits in table 10.2.4.1.

3. If no reference to control circuits exist in the instruction manual, apply an ac sine wave of 4 V p-p (2.828 V rms) at a frequency of 10 kHz to CHANNEL 1 vertical input.

4. Set the controls of the oscilloscope to the default values given in the NOTES, Item 4, p.1. A display of 100 sine waves (ten cycles per division) should fill the screen.

5. Vary the intensity control and note if the display remains clear and sharp at all magnitudes of intensity below the point of beam halo. Record the compliance (or lack of compliance) of this specification in table 10.2.4.1.

Table 10.2.4.1 Focus

Measurement Description	Measurement Data	Estimated Measurement Uncertainty	Specification Limits Min.	Max.	Units
Front-panel focus control?	____________	N/A	Yes		
Auto. focus in manual?	____________	N/A	Yes[1]		
Sine display stays sharp?	____________	N/A	Yes[1]		

[1] If either a reference is made to the existence of control circuits in the instruction manual *or* a display of 100 sine waves remains clear and sharp at all magnitudes of intensity below the point of beam halo, then this section of the procedure is successful.

10.2 Cathode Ray Tube (CRT)

10.2.4.2 Astigmatism

Specification:

An astigmatism manual control or automatic circuitry shall be provided to control the roundness of the electron beam spot.

Equipment:

Items	Model
Precision Optical Comparator (15X)	Bishop Model 3561 or equivalent
Manufacturer's Instruction Manual	Supplied by Manufacturer

Procedure:

1. Note the existence of a front-panel astigmatism control. Record the compliance (or lack of compliance) of this specification in table 10.2.4.2.

2. Read the instruction manual supplied with the instrument and note the existence of automatic astigmatism control circuits to control the roundness of the electron beam spot. Record the existence of the presence of such circuits in table 10.2.4.2.

3. Place the oscilloscope in the X-Y display mode. Do not connect any cables to the inputs of the oscilloscope. There should be a single spot on the screen of the oscilloscope. Set the vertical and horizontal position controls such that the spot is in the center of the screen at position 1 on the figure below. Focus the beam until the spot attains minimum size. Adjust the intensity for normal viewing.

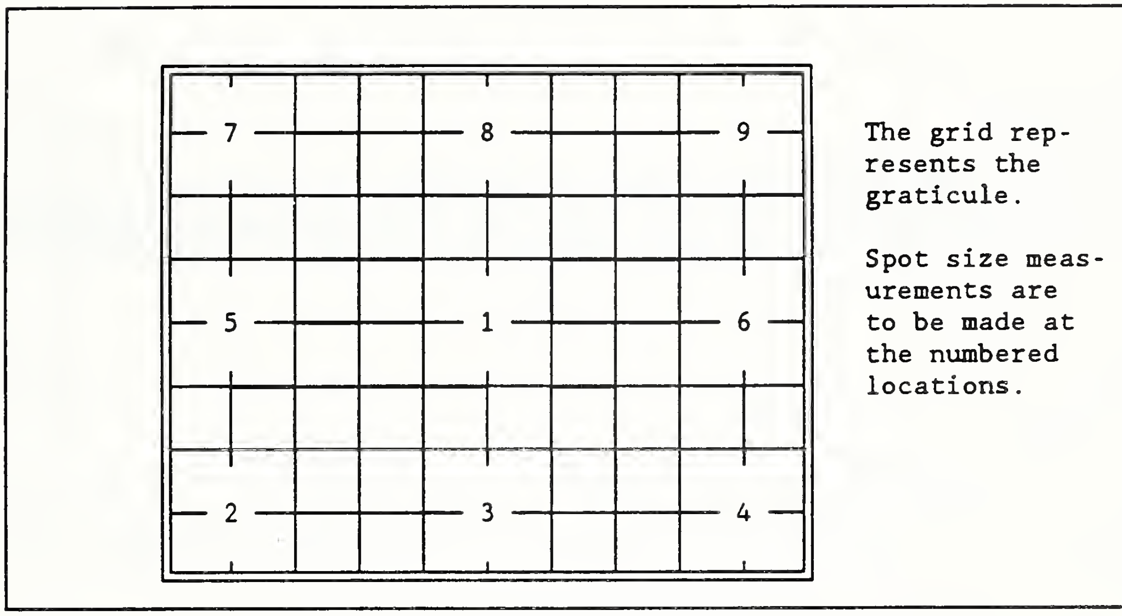


Figure 10.2.4.2 Location for measurement of astigmatism

4. Use the precision optical comparator to observe the shape of the spot. Vary the intensity and the focus controls to obtain a spot below the point of beam halo. The spot should remain circular throughout the adjustment range of the controls. Record the compliance (or lack of compliance) of this specification in table 10.2.4.2.

Table 10.2.4.2 Astigmatism

Measurement Description	Measurement Data	Estimated Measurement Uncertainty	Specification Limits Min.	Specification Limits Max.	Units
Front-panel astig control?	______	N/A	Yes[1]		
Auto. astig. in manual?	______	N/A	Yes[1]		
Spot shape is circular?	______	N/A	Yes[1]		

[1] If a front panel astigmatism control is provided *or* a reference is made to the existence of control circuits in the instruction manual *or* a display of 100 sine waves remains clear and sharp at all magnitudes of intensity below the point of beam halo, then this section of the procedure is successful.

10.2 Cathode Ray Tube (CRT)

10.2.4.3 Intensity

Specification:

A front panel intensity control shall be provided. It shall provide for optimum intensity of the displayed signal and shall provide continuous range from extinguished beam to at least greater than the point of beam halo.

Equipment:

Items	Model
None	

Procedure:

1. Note the existence of a front-panel intensity control. Record the compliance (or lack of compliance) of this specification in table 10.2.4.3.

2. Vary the control such that the beam intensity is minimum. Record in table 10.2.4.3 if the beam is extinguished.

3. Vary the control such that the beam intensity is maximum. Record in table 10.2.4.3 if the beam is greater than the point of halo.

Table 10.2.4.3 Intensity

Measurement Description	Measurement Data	Estimated Measurement Uncertainty	Specification Limits Min.	Specification Limits Max.	Units
Front-panel inten control?	____________	N/A	Yes		
Inten. may be extinguished?	____________	N/A	Yes		
Inten. may be set to halo?	____________	N/A	Yes		

10.2 Cathode Ray Tube (CRT)

10.2.4.3.1 Intensity (beam current limit)

Specification:

An automatic intensity limit shall be provided which limits beam current under all applications to a level which will not damage the CRT. Response time shall insure viewing of low duty cycle fast risetime pulses.

Equipment:

Items	Model
Manufacturer's Instruction Manual	Supplied by Manufacturer
Pulse Generator	H-P Model 8082A or equivalent
BNC Male to BNC Male Coaxial Cable 36 inches (91.4 cm)	Tektronix P/N 012-0482-00 or equivalent

Procedure:

1. Read the instruction manual supplied with the instrument to determine the existence of an automatic intensity limit which will limit the beam current all degrees of intensity settings. Record the existence of the presence of such circuits in table 10.2.4.3.1.

2. Determine if the intensity limiting function performs properly. Set the controls of the oscilloscope to the default values given in the Notes, Item 4. Change the following controls from their default values to that shown below.

   Vertical Controls (Both Channels)
   - IMPEDANCE — 50 Ω

   Triggering Controls (both time bases)
   - SOURCE — External
   - TRIGGER MODE — External 1

   Sweep Controls
   - A TIME/DIVISION — 10 ns

3. Set the pulse generator as shown below.

   Timing
   - PULSE WIDTH — 10 ns
   - PERIOD — 0.1 μs

   Level
   - LOW LEVEL — -2 V
   - HIGH LEVEL — +2 V

4. Connect one cable between the OUTPUT connector of the pulse generator and the CHANNEL 1 input of the storage oscilloscope. Connect the second cable between the +TRIG OUT connector of the pulse generator and the EXTERNAL 1 trigger connector of the storage oscilloscope.

5. Assure that the intensity is at a sufficient level such that the storage oscilloscope presents a well-defined representation of the pulse. Assure that the storage oscilloscope is properly triggered and displays the waveform as shown in the figure below.

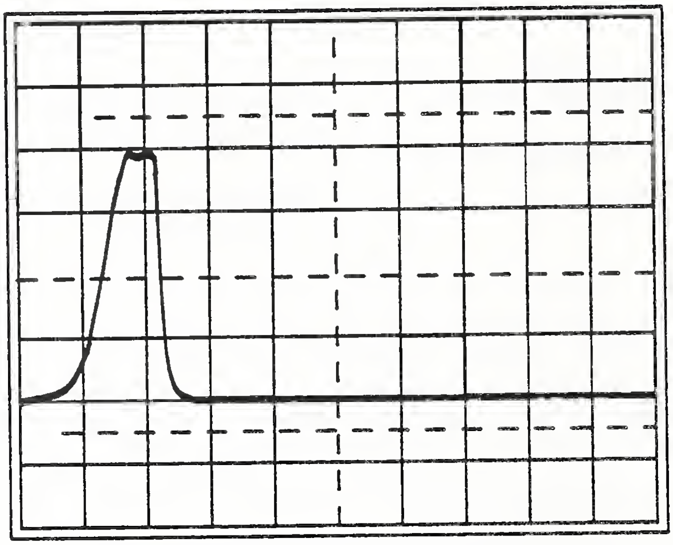


Figure 10.2.4.3.1 Display for intensity (beam current limit)

6. Change the controls of the pulse generator as follows:

Timing	
PERIOD	10 ms

7. Assure that the pulse may still be seen. Record in table 10.2.4.3.1 that the pulse is still visible.

Table 10.2.4.3.1 Intensity (Beam Current Limit)

Measurement Description	Measurement Data	Estimated Measurement Uncertainty	Specification Limits Min.	Max.	Units
Inten. limit in manual?	______________	N/A	Yes[1]		
Trace visible at 10 ms per.?	______________	N/A	Yes[1]		

[1] If either a reference is made to the existence of an intensity beam current limiting feature in the instruction manual *or* a display of a 10 ns duration pulse with a period of 10 ms is visible, then this section of the procedure is successful.

10.2 Cathode Ray Tube (CRT)

10.2.4.4 Trace Rotation

Specification:

A control of recessed common screwdriver type shall be provided to rotate the trace about the horizontal axis. Rotation range shall be adequate to align the trace to the horizontal graticule lines. Sufficient offset shall be introduced to compensate for variations in the earth's magnetic field with at least ±2 degrees overcompensation.

Equipment:

Items	Model
Trace Rotation Alignment Tool	NIST supplied
Screwdriver, 3" long, 7/32 diameter	Stanley No. 1006 732SC088 or equivalent

Procedure:

1. Assure that the control for the trace rotation is of a common screwdriver type and is recessed behind the panel. Record the compliance (or lack of compliance) of this specification in table 10.2.4.4.

2. Rotate the trace rotation control and assure that the trace may be aligned to the center horizontal graticule line. Record the compliance (or lack of compliance) of this specification in table 10.2.4.4.

3. Place the trace rotation alignment tool on the face of the storage oscilloscope cathode-ray tube (CRT) such that the reference line, marked with the circles, aligns with the horizontal graticule line engraved on the CRT. The crosshatching encloses and area between two lines that are at ±2° from the reference line.

4. Rotate the trace rotation control from limit to limit and assure that the trace may be aligned such that it is outside the crosshatched area. Record the compliance (or lack of compliance) of this specification in table 10.2.4.4.

Table 10.2.4.4 Trace Rotation

Measurement Description	Measurement Data	Estimated Measurement Uncertainty	Specification Limits Min.	Max.	Units
Control is proper type?	____________	N/A	Yes		
Trace aligned to horizontal?	____________	N/A	Yes		
Trace may be rotated ±2°?	____________	±0.5°	-2	+2	degree

10.2.4.5 Graticule Illumination

Specification:

A front panel control shall be provided. It shall provide variable graticule illumination from zero to greater than optimum illumination.

Equipment:

Items	Model
None	

Procedure:

1. Assure that a front panel control for the control of the graticule illumination is provided. Record the compliance (or lack of compliance) of this specification in table 10.2.4.5.

2. Set the control such that the graticule illumination is minimum. Assure that the illumination of the graticule is zero. Record the compliance (or lack of compliance) of this specification in table 10.2.4.5.

3. Set the control such that the graticule illumination is maximum. Assure that the illumination of the graticule is greater than optimum illumination. (Greater than optimum illumination may be defined as the point when the intensity of the graticule lines exceeds the intensity of the trace normally presented on the oscilloscope CRT.) Record the compliance (or lack of compliance) of this specification in table 10.2.4.5.

Table 10.2.4.5 Graticule Illumination

Measurement Description	Measurement Data	Estimated Measurement Uncertainty	Specification Limits Min.	Specification Limits Max.	Units
Front panel control?	______	N/A	Yes		
Min. illu'm'n is zero?	______	N/A	Yes		
Max. illu'm'n excessive?	______	N/A	Yes		

10.2 Cathode Ray Tube (CRT)

10.2.5 Auto-Setup/Auto-Scale

Specification:

A front panel control shall be provided which when activated provides an initial setup and displays a stable, automatically triggered display for an unknown repetitive signal at an input channel. All basic settings for vertical deflection, horizontal deflection, and triggering shall automatically be made.

Equipment:

Items	Model
Pulse Generator	H-P Model 8082A or equivalent
BNC Male to BNC Male Coaxial Cable 36 inches (91.4 cm) 2 ea.	Tektronix P/N 012-0482-00 or equivalent

Procedure:

1. Assure that a front panel control is provided that, when activated, displays a stable, automatically triggered display of each input channel.

2. Determine if the automatic setup and scaling feature performs by initiating the function for various input amplitudes and periods. Set the controls of the oscilloscope to the default values given in the NOTES, Item 4, p.1. Change the following controls from their default values to that shown below.

   Vertical Controls (both channels)
   INPUT IMPEDANCE 50 Ω

3. Set the pulse generator as shown below.

   Timing
   PULSE DURATION 10 ns
   PERIOD 100 ns

   Level
   LOW LEVEL -2 V
   HIGH LEVEL +2 V

4. Connect one cable between the OUTPUT connector of the pulse generator and the CHANNEL 1 input of the storage oscilloscope. Connect the second cable between the -TRIG OUT connector of the pulse generator and the EXTERNAL 1 trigger connector of the storage oscilloscope.

5. Initiate the automatic setup feature. Note if a stable, automatically triggered display appears on the screen of the CRT. Record the compliance (or lack of compliance) of this specification in table 10.2.5.

6. Change the output amplitude of the pulse generator as follows:

Level	
LOW LEVEL	-1.0 V
HIGH LEVEL	-1.5 V

7. Initiate the automatic setup feature. Note if a stable, automatically triggered display appears on the screen of the CRT. Record the compliance (or lack of compliance) of this specification in table 10.2.5.

8. Change the output amplitude of the pulse generator as follows:

Timing	
PULSE DURATION	10 μs
PERIOD	100 μs

9. Initiate the automatic setup feature. Note if a stable, automatically triggered display appears on the screen of the CRT. Record the compliance (or lack of compliance) of this specification in table 10.2.5.

Table 10.2.5 Auto-Setup/Auto-Scale

Measurement Description	Measurement Data	Estimated Measurement Uncertainty	Specification Limits Min.	Specification Limits Max.	Units
Front panel control?	______	N/A	Yes		
Auto-setup 10ns, ±2V	______	N/A	Yes		
Auto-setup -1 to -1.5 V	______	N/A	Yes		
Auto-setup 10μs, -1.5 V	______	N/A	Yes		

10.2 Cathode Ray Tube (CRT)

10.2.6 Delta Time and Delta Voltage Measurements

Specification:

Cursor facilities with CRT readout shall be provided for both time and amplitude measurements. When activated, two independent, movable cursors will be superimposed across the CRT display. The alphanumeric CRT readout will display the equivalent voltage or time represented by the separation between the two cursors. Readout will account for any probe attenuation. Movability of the cursors is not required for analog storage oscilloscopes when in the storage mode.

Equipment:

Items	Model
Probe, 10:1	Supplied by Manufacturer

Procedure:

1. Assure that there are provided two cursors, for time measurements and for amplitude measurements. Record the compliance (or lack of compliance) of this specification in table 10.2.6.

2. Assure that the two cursors may be moved across the CRT display and that an alphanumeric readout is present to represent the position of the cursors. Record the compliance (or lack of compliance) of this specification in table 10.2.6.

3. Change the vertical controls to various ranges of VOLTS/DIV and assure that the alphanumeric readout changes to represent the voltage per division set by the controls. Record the compliance (or lack of compliance) of this specification in table 10.2.6.

4. Change the sweep control to various ranges of time base A TIME/DIV and assure that the alphanumeric readout changes to represent the time per division set by the controls. Record the compliance (or lack of compliance) of this specification in table 10.2.6.

5. Set the controls to the of the oscilloscope to the default values given in the NOTES, Item 4, p.1. Plug the 10:1 probe into the CHANNEL 1 connector. Assure that the alphanumeric readout for CHANNEL 1 increases by a factor of 10 to reflect the presence of the probe at the CHANNEL 1 input. Remove the probe from the CHANNEL 1 connector and plug the probe into the CHANNEL 2 connector.

6. Assure that the alphanumeric readout for CHANNEL 2 increases by a factor of 10 to reflect the presence of the probe at the CHANNEL 2 input. Record the compliance (or lack of compliance) of this specification in table 10.2.6.

Table 10.2.6 Delta Time and Delta Voltage Measurements

Measurement Description	Measurement Data	Estimated Measurement Uncertainty	Specification Limits Min.	Max.	Units
Are there two cursor sets?	________	N/A	Yes		
Cursors move over display?	________	N/A	Yes		
Vert. readout correct?	________	N/A	Yes		
Time readout correct?	________	N/A	Yes		
Probe changes CH 1 readout?	________	N/A	Yes		
Probe changes CH 2 readout?	________	N/A	Yes		

10.2 Cathode Ray Tube (CRT)

10.2.6.1 Delta Time and Delta Voltage Accuracy

Specification:

a. *±2 percent of full scale; for delta time intervals measured with the cursors vertically positioned anywhere on the graticule.*

b. *±2 percent of full scale; for delta voltage intervals measured with the cursors horizontally positioned anywhere on the graticule.*

Equipment:

Items	Model
Time Mark Generator	Tektronix TG 501 or equivalent
DC Voltage Calibrator	Fluke Model 5101B or equivalent
BNC Male to BNC Male Coaxial Cable 36 inches (91.4 cm) 2 ea.	Tektronix P/N 012-0482-00 or equivalent
BNC Female to Banana Adapter	Pomona 1452 or equivalent

Procedure

NOTE: The average of 5 measurements will often be used to minimize the uncertainty in establishing an oscilloscope parameter. The imprecision for a confidence level of 0.90 with this number of measurements is $0.95s \simeq s$, where s is the estimated standard deviation. In general, the estimated total uncertainty is $\epsilon = \epsilon_{ca} + s$, where ϵ_{ca} is the uncertainty of the calibrator, time mark generator, etc. If $\epsilon_{ca} \ll s$, ϵ_{ca} will be neglected.

Part 1: Delta Time Accuracy

1. Connect the time mark generator to Channel 1 as shown in figure 10.2.6.1a.

2. Set the time mark generator for a 1 μs pulse spacing.

3. Set the vertical deflection sensitivity of the oscilloscope to 500 mV/div and the input coupling to DC and 50 Ω ON for Channel 1. Set the oscilloscope sweep speed to 1 μs/div. Position the marker pulses to coincide approximately with the vertical graticule lines.

4. Using the cursors in the delta time mode, position the cursors so that the cursors lie exactly on the marker pulses located on the <u>second</u> and <u>sixth</u> graticule lines (counting from the left side of the storage oscilloscope screen).

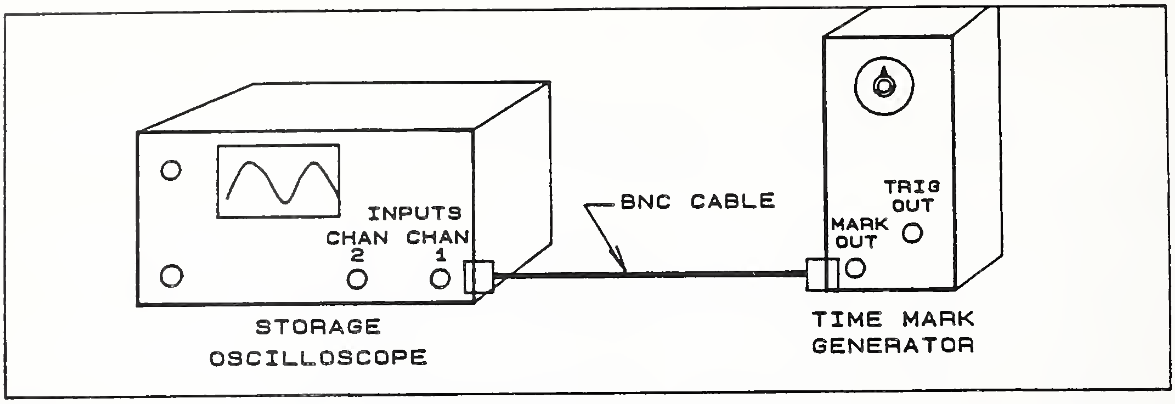


Figure 10.2.6.1a Test setup for measuring the delta time cursor accuracy

5. Record the readout into the 3rd column, row 1, of table 10.2.6.1a.

6. Offset the cursor spacing an arbitrary amount, and then reposition the cursors as before. Record the new readout into the 3rd column of the table.

7. Repeat step 5 three more times, so that a total of 5 readings have been recorded. In order to minimize the observer's influence of a previous readout, the readout intensity should be decreased below the level of readability each time the cursor positions are readjusted.

8. Use a suitable hand-held calculate to average the five readings and to calculate the standard deviation, s. Enter the value of s into column 4 into table 10.2.6.1a.

9. Position the cursors so that the cursors lie exactly on the marker pulses located on the <u>fifth</u> and <u>ninth</u> graticule lines. Repeat steps 5, 6, 7 and 8, recording the readout in row 2 of table 10.2.6.1a.

10. Position the cursors so that they lie exactly on the marker pulses located on the <u>second</u> and <u>ninth</u> graticule lines. Repeat steps 5, 6, 7 and 8, recording the readouts in row 3 of the table.

Part 2: Delta Voltage Accuracy

11. Set the vertical deflection sensitivity of the storage oscilloscope to 50 mV/div and the input coupling to DC and 50 Ω OFF for Channel 1.

12. Set the dc to 0.0 mV dc, and connect the calibrator output to Channel 1 as shown in figure 10.2.6.1b and position the sweep trace for exactly 0.0 mV vertical deflection.

13. Set the dc calibrator output to 150 mV and reverse its polarity several times. Note that the storage oscilloscope trace should be vertically deflected ±3 divisions.

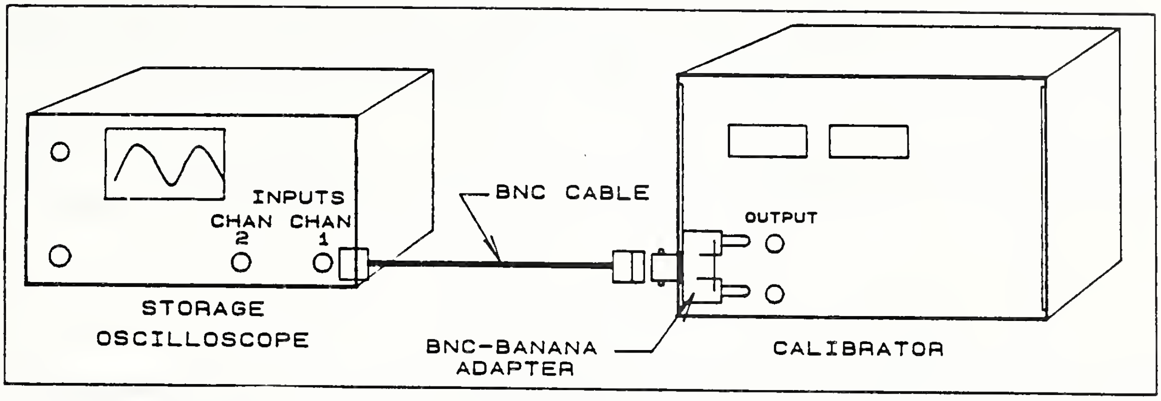


Figure 10.2.6.1b Test setup for measuring the delta voltage cursor accuracy

14. Turn the delta voltage cursors on and adjust the spacing and offset so that the cursor lines coincide with the ±150 mV horizontal traces caused by changing the calibrator's output polarity. Adjust the display intensity of the storage oscilloscope for best resolution.

15. Record the readout of the delta voltage in the 3rd column, row 1, of table 10.2.6.1b.

16. Offset the cursor spacing an arbitrary amount, then reposition the cursors as before. Record the new readout in the 3rd column of the table.

17. Repeat step 16 three more times, so that a total of 5 readings have been recorded. In order to minimize the observer's influence of previous readouts, the readout intensity should be decreased below the level of readability each time the cursor positions are readjusted.

18. Use a suitable hand-held calculator to average the five readings and to calculate the standard deviation, s. Enter the value of s in table 10.2.6.1b.

19. Set the dc calibrator to 0.0 mV dc, and check to see that the sweep trace has exactly 0.0 mV vertical deflection. Carefully readjust the sweep trace vertical position, if necessary.

20. Set the dc calibrator output to 50 mV dc and reverse its polarity several times. Note that the storage oscilloscope trace should be vertically deflected ±1 division.

21. Adjust the spacing and offset of the delta voltage cursors on and adjust the spacing and offset so that the cursor lines coincide with the ±50 mV horizontal traces caused by changing the calibrator's output polarity. Adjust the display intensity of the storage oscilloscope for best resolution.

22. Repeat steps 16 through 18, recording the outputs in row 2 of table 10.2.6.1b.

Table 10.2.6.1a Delta Time Measurement

Marker Spacing	Nominal Cursor Positions	Delta Time Measurements	Uncertainty $\epsilon \simeq s^*$	Specification Limits µs min.	max.
1 µs	2, 6 µs	______ ______ ______ ______ ______ Av______		3.92	4.08
1 µs	5, 9 µs	______ ______ ______ ______ ______ Av______		3.92	4.08
1 µs	2, 9 µs	______ ______ ______ ______ ______ Av______		6.86	7.14

* The maximum uncertainty of the marker spacings shown in the table is ±0.0007 µs. Therefore, the uncertainty of the marker generator, ϵ_{ca}, is so small that it can be neglected (omitted).

Table 10.2.6.1b Delta Voltage Measurements

Calibrator Outputs $\pm E_c$	"Delta" Input Voltage $(2E_c)$	Delta Voltage Measurements	Uncer-tainty $\epsilon \approx s$*	Specification Limits min.	max.
±150 mV	300 mV	______ ______ ______ ______ ______ Av______		294 mV	306 mV
±50 mV	100 mV	______ ______ ______ ______ ______ Av______		98 mV	102 mV

* The uncertainties, ϵ_{ca}, of the input voltages of 300 mV and 100 mV are ±0.045 mV and ±0.0085 mV, respectively. These quantities are so small that they can be neglected.

10.2 Cathode Ray Tube (CRT)

10.2.6.2 Alphanumeric CRT Readouts

Specification:

All readout and cursor displays on the CRT shall be clear and stable to the eye for any input signal and setting combinations.

Equipment:

Items	Model
Pulse Generator	H-P Model 8082A or equivalent
BNC Male to BNC Male Coaxial Cable 36 inches (91.4 cm) 2 ea.	Tektronix P/N 012-0482-00 or equivalent

Procedure:

1. Connect one cable between the OUTPUT connector of the pulse generator and the CHANNEL 1 input of the storage oscilloscope. Connect the second cable between the -TRIG OUT connector of the pulse generator and the EXTERNAL 1 trigger connector of the storage oscilloscope as shown in figure 10.2.6.2a.

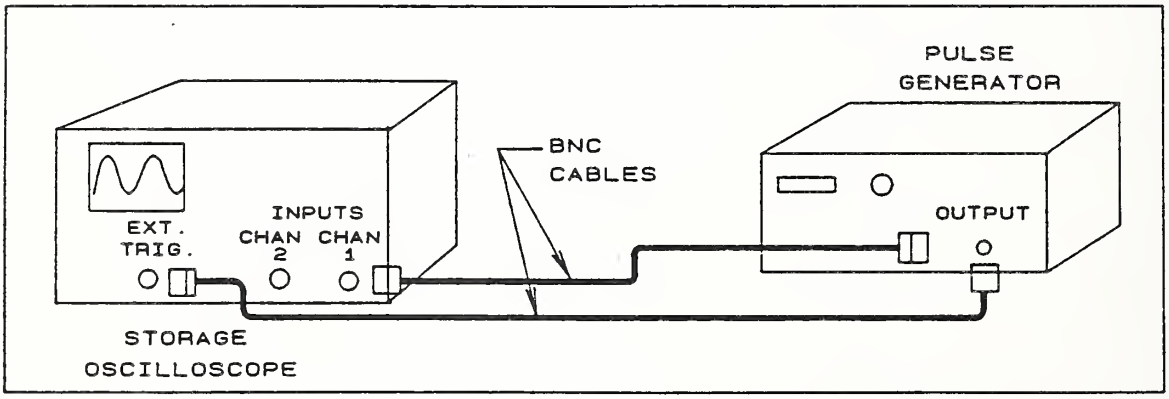


Figure 10.2.6.2a Display for measuring the alphanumeric CRT readout

2. Set the controls of the oscilloscope to the default values given in the , Item 4. Change the following controls from their default values to that shown below.

Vertical Controls (Both Channels)

IMPEDANCE	50 Ω

Triggering Controls (both time bases)

SOURCE	External
TRIGGER MODE	External 1

Sweep Controls

A TIME/DIVISION	10 ns

3. Set the pulse generator as shown below.

Timing

PULSE DURATION	10 ns
PERIOD	100 ns

Level

LOW LEVEL	-2 V
HIGH LEVEL	+2 V

4. Assure that the intensity of the trace and the readout are such that the storage oscilloscope presents a well-defined representation of the pulse, readout, and cursor displays. Assure that the storage oscilloscope is properly triggered and displays the waveform as shown in the figure below.

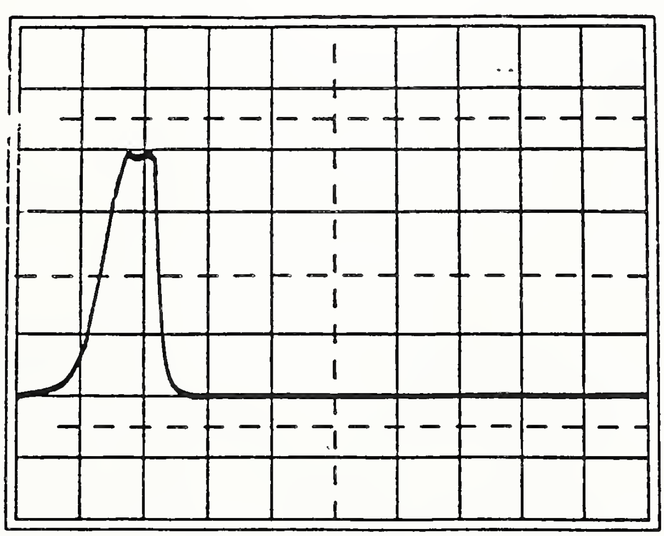


Figure 10.2.6.2b Display for measurement of alphanumeric CRT readouts

5. Assure that the cursor and readout displays are clear and stable. Record the compliance (or lack of compliance) of this specification in table 10.2.6.2.

6. Change the controls of the pulse generator as follows:

   Timing
   PERIOD 1.0 ms

7. Assure that the cursor and readout displays are clear and stable. Record the compliance (or lack of compliance) of this specification in table 10.2.6.2.

Table 10.2.6.2 Alphanumeric CRT Readouts

Measurement Description	Measurement Data	Estimated Measurement Uncertainty	Specification Limits Min.	Specification Limits Max.	Units
Readouts clear at 10ns?	____________	N/A	Yes		
Readouts clear at 1.0ms?	____________	N/A	Yes		

10.2 Cathode Ray Tube (CRT)

10.2.6.2.1 Display Readout Jitter

Specification:

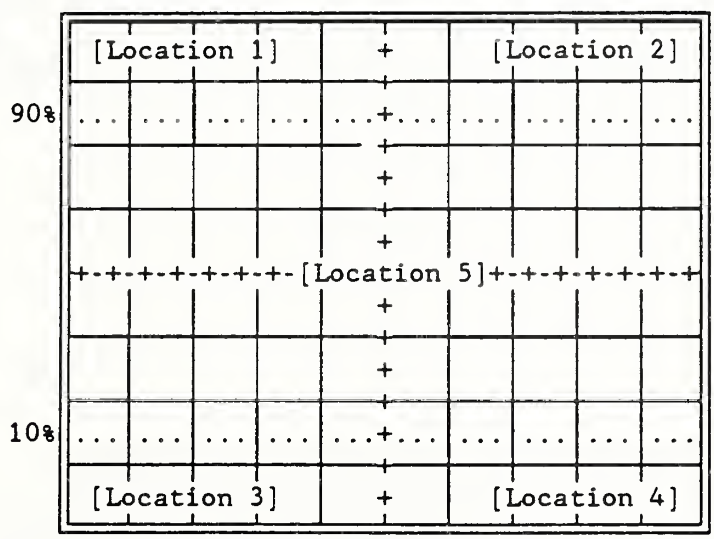
The jitter of any alphanumeric character shall not be greater than 0.10 minor divisions.

Equipment:

Items	Model
Precision Optical Comparator (15X)	Bishop Model 3561 or equivalent
Manufacturer's Instruction Manual	Supplied by Manufacturer

Procedure:

1. Select up to five locations to perform the display readout jitter measurement. Record the locations on the on the figure below.



The grid represents the graticule.

The approximate location for the alphanumeric readout jitter tests are shown.

Figure 10.2.6.2.1 Locations for measurement of display readout jitter

2. Use the optical comparator to observe an alphanumeric character at each of the five locations. Note the amplitude of movement of a small feature on an alphanumeric character displayed. Candidate features may include the dot of the character "i" or the serif of a letter.

3. Read the amplitude of the jitter, in millimeters, as observed through the optical comparator. Count the number of millimeters per minor division, as presented on the display of the storage oscilloscope. Divide the amplitude of the jitter, in millimeters, by the number of millimeters per minor division to convert the observation to minor divisions. Record the amplitude of the jitter, in minor divisions, in table 10.2.6.2.

Table 10.2.6.2.1 Display Readout Jitter

Measurement Description	Measurement Data	Estimated Measurement Uncertainty	Specification Limits Min.	Max.	Units
Jitter at 1st location	________	±0.05	-0.10	0.10	Minor Div
Jitter at 2nd location	________	±0.05	-0.10	0.10	Minor Div
Jitter at 3rd location	________	±0.05	-0.10	0.10	Minor Div
Jitter at 4th location	________	±0.05	-0.10	0.10	Minor Div
Jitter at 5th location	________	±0.05	-0.10	0.10	Minor Div

10.2 Cathode Ray Tube (CRT)

10.2.6.2.2 Numeric and Uppercase Letters

Specification:

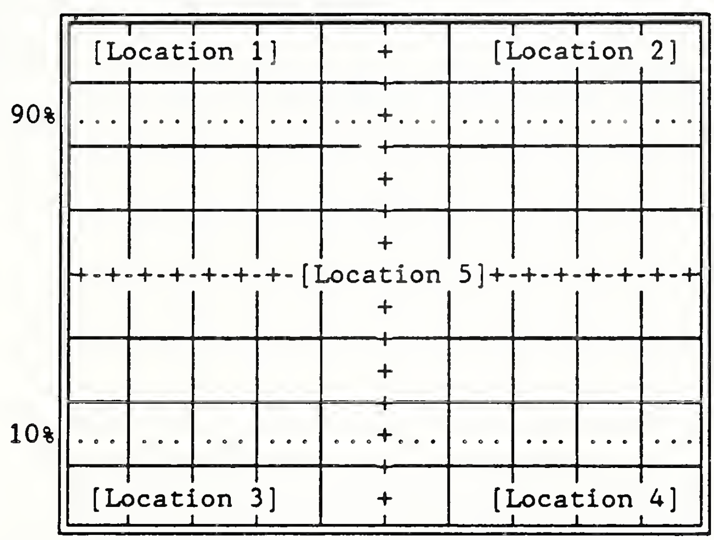
Minimum height shall be 1.5 minor divisions.

Equipment:

Items	Model
Precision Optical Comparator (15X)	Bishop Model 3561 or equivalent
Manufacturer's Instruction Manual	Supplied by Manufacturer

Procedure:

1. Select up to five locations to measure the height of the numeric and uppercase letters. At least two uppercase letters and three numeric characters should be measured. Record the locations on the on the figure below.



The grid represents the graticule.

The approximate location for the height of the numeric and uppercase letters are shown.

Figure 10.2.6.2.2 Locations for display of numeric and uppercase letters

2. Use the optical comparator to observe an alphanumeric character at five possible locations. Note the height of the numeric and uppercase character displayed.

3. Read the height of the numeric and uppercase letters, in millimeters, as observed through the optical comparator. Count the number of millimeters

per minor division, as presented on the display of the storage oscilloscope. Divide the amplitude of the height of the numeric and uppercase letters, in millimeters, by the number of millimeters per minor divisions to convert the observation to minor divisions. Record the height of the numeric and uppercase letters, in minor divisions, in table 10.2.6.2.2.

Table 10.2.6.2.2 Numeric and Uppercase Letters

Measurement Description	Measurement Data	Estimated Measurement Uncertainty	Specification Limits Min.	Max.	Units
Height at 1st location	______	±0.05	1.5		Minor Div
Height at 2nd location	______	±0.05	1.5		Minor Div
Height at 3rd location	______	±0.05	1.5		Minor Div
Height at 4th location	______	±0.05	1.5		Minor Div
Height at 5th location	______	±0.05	1.5		Minor Div

10.2 Cathode Ray Tube (CRT)

10.2.6.2.3 Lowercase Letters and Mathematical Symbols

<u>Specification:</u>

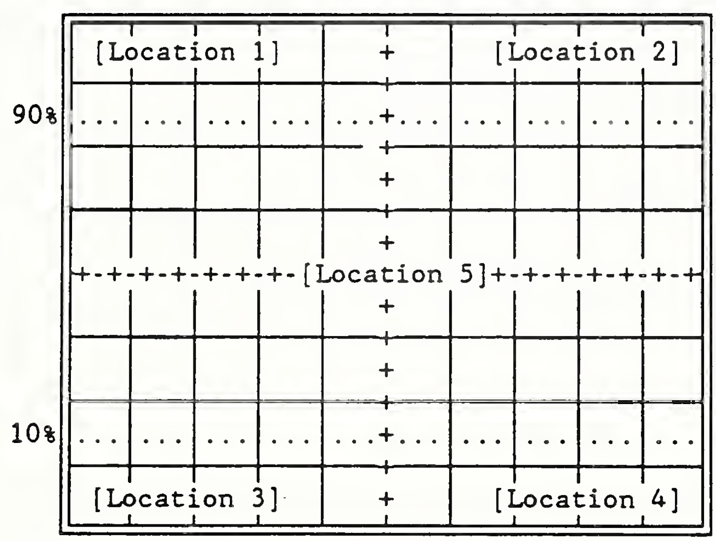
Minimum height shall be 1.0 minor division.

<u>Equipment</u>:

Items	Model
Precision Optical Comparator (15X)	Bishop Model 3561 or equivalent
Manufacturer's Instruction Manual	Supplied by Manufacturer

<u>Procedure</u>:

1. Select up to five locations to measure the height of the lowercase letters and mathematical symbols. At least three lowercase letters and two mathematical symbols must be measured. Record the locations on the figure below.



The grid represents the graticule.

The approximate location for the measurement of the height of the lowercase letters and mathematical symbols.

Figure 10.2.6.2.3 Locations for display of lowercase letters and mathematical symbols

2. Use the optical comparator to observe an alphanumeric character at each of the possible locations. Note the height of the lowercase letters and mathematical symbols.

3. Read the height of the lowercase letters and mathematical symbols, as observed through the optical comparator. Count the number millimeters per minor division, as presented on the display of the storage oscilloscope. Divide the height of the lowercase letters and mathematical symbols, in millimeters, by the number of millimeters per minor divisions to convert the observation to minor divisions. Record the height of the lowercase letters and mathematical symbols, in minor divisions, in table 10.2.6.2.3.

Table 10.2.6.2.3 Lowercase Letters and Mathematical Symbols

Measurement Description	Measurement Data	Estimated Measurement Uncertainty	Specification Limits Min.	Max.	Units
Height at 1st location	____________	±0.05	1.0		Minor Div
Height at 2nd location	____________	±0.05	1.0		Minor Div
Height at 3rd location	____________	±0.05	1.0		Minor Div
Height at 4th location	____________	±0.05	1.0		Minor Div
Height at 5th location	____________	±0.05	1.0		Minor Div

10.2 Cathode Ray Tube (CRT)

10.2.6.3 Vertical and Horizontal Readout

Specification:

A readout of the vertical and horizontal scale or scale factors shall be displayed on the CRT.

Equipment:

Items	Model
None	

Procedure:

1. Assure that the storage oscilloscope is provided with a readout of the vertical and horizontal scale or scale factor displayed on the CRT.

2. Record the compliance (or lack of compliance) of this specification in table 10.2.6.3.

Table 10.2.6.3 Vertical and Horizontal Readout

Measurement Description	Measurement Data	Estimated Measurement Uncertainty	Specification Limits Min.	Specification Limits Max.	Units
Vert and horiz readouts?	____________	N/A	Yes		

10.3 Vertical Section

10.3.1 Vertical Input Channels

Specification:

Two channels with identical performance characteristics shall be provided.

Equipment:

Items	Model
None	

Procedure:

1. Assure that the storage oscilloscope is provided with two distinctly marked vertical input channels. Each input channel is to consist of an input connector, method for setting sensitivity (attenuator), and associated alphanumeric readout capability.

2. Record the compliance (or lack of compliance) of this specification table 10.3.1.

Table 10.3.1 Vertical Input Channels

Measurement Description	Measurement Data	Estimated Measurement Uncertainty	Specification Limits Min.	Specification Limits Max.	Units
Two input channels?	________	N/A	Yes		

10.3 Vertical Section

10.3.2 Bandwidth

Specification:

The -3 dB bandwidth of each vertical channel shall be from dc to at least 100 MHz with and without the probes attached and at all attenuator settings. Aberrations/flatness across the bandwidth shall not be greater than ±0.5 dB.

Equipment:

Items	Model
DC Voltage Calibrator	Fluke Model 5101B Calibrator or equivalent
AC Voltage Calibrator	Fluke Model 5200A Calibrator or equivalent
Sine-Wave Generator	Tektronix SG 503 or equivalent
10 dB Attenuator	Weinschel Model 50-10 or equivalent
36"(91 cm) Coaxial Cable (Male BNC Connectors)	Tektronix P/N 012-0482-00 or equivalent
Attenuator, 10:1	NIST Special Attenuator, dc-200 kHz $Z_{in} \approx 8$ kΩ, or equivalent
Calculator	Sharp Model El-5001 and Instructional Manual, or equivalent
Peak-to-peak Detector	NIST Special Detector
Digital Multimeter	Fluke Model 8506A or equivalent
10:1 Voltage Divider Probes with BNC tip adapters	Supplied by Oscilloscope Manufacturer
Amplifier, RF	ENI Model 3100 LA or equivalent
Terminator, 50 Ω, 40 Watt	NIST Supplied Fixture

NOTES (1) For both Channel 1 and Channel 2, the flatness of the frequency response for any given amplifier range is the oscilloscope response (gain) for all test frequencies, relative to the response at the reference frequency. The reference frequency is 50 kHz for the dc - 200 kHz range and 500 kHz for the 500 kHz - 100 MHz range.

(2) If the unit under test (UUT) is a digital oscilloscope, use the average mode and average approximately 6 acquisitions before making a measurement. When using an analog storage oscilloscope, there generally is no advantage in using the storage feature except when capturing a single transient or when viewing very low frequency (<1 Hz) repetitive waveforms.

(3) The cursors will often be used in the delta voltage or delta time mode to make 5 or 6 successive measurements of a displayed quantity. In order to minimize the observer's influence of previous readouts

when adjusting cursor positions, the readout intensity should be decreased below the level of readability each time the cursor positions are readjusted.

(4) In the following procedures, it has been assumed that use of cursors is necessary to arrive at the peak-to-peak amplitude values. Generally, the accuracy of a <u>single</u> measurement using cursors is too low to establish parameter values. Therefore, statistical methods are prescribed in the procedures, starting with several measurements of each oscilloscope parameter, to decrease the uncertainty of their values.

(5) If the digitizing oscilloscope provides a readout of the peak-to-peak amplitude value being measured, it is unnecessary to use the cursors. Then, a single measurement can be used to arrive at the value of "V_r" or "A_v" in the tables.

(6) The single digitized value should not be used above 1 MHz, however. Also, when used the imprecision term in the tables (0.8s or s) should be replaced with the inaccuracy of the digitizer. This inaccuracy is estimated to be, approximately: full scale voltage ÷ 2^N, where N = no. of bits. 2^N equals 256 and 1024 for 8 and 10 bit digitizers, respectively.

(7) Bipolar dc voltages are applied to the oscilloscope under test to obtain its dc response for a given range. The peak-to-peak response is obtained by adding the magnitudes (disregard signs) of the readouts of the digitized voltage for each polarity of voltage.

<u>Procedure</u>:

Summary of Procedure:

The procedure for "10.3.2 Bandwidth" is quite extensive and consists of 4 parts. They are:

Part 1: DC-200 kHz, for Channel 1
Part 2: 50 kHz-100 MHz, for Channel 1
Part 3: DC-200 kHz, for Channel 2
Part 4: 50 kHz-100 MHz, for Channel 2.

Table numbers for Channel 1 end in a-1, and table numbers for Channel 2 end in a-2. Except for these differences, Parts 1 and 3 are identical, and Parts 2 and 4 are identical.

It is helpful to outline the procedural steps used in Part 1. First, the vertical response is measured at the 50 kHz reference frequency for each input range (Table 10.3.2a-1 when no probe is used and table 10.3.2l-1 when a probe is used). Second, the dc response is measured for each input range (Tables 10.3.2b-1 through 10.3.2p-1, except for 10.3.2l-1). tables 10.3.2m-1 through 10.3.2p-1 apply to measurements using the oscilloscope's probe. Third, the vertical response is measured at all voltage ranges for several frequencies in

the 10 Hz -200 kHz range. (Tables 10.3.2b-1 through 10.3.2k-1 and 10.3.2o-1, 10.3.2p-1). A signal at a frequency of 500 kHz serves as the reference for the 5 V and 10 V ranges in Part 2, hence, the reason for the 500 kHz measurement in tables 10.3.2m-1 and 10.3.2n-1.

Part 2 covers the frequency range of 500 kHz to 100 MHz. For input ranges up to 1 V/div, all vertical response measurements are compared directly to a 50 kHz reference (Tables 10.3.2aa-1 through 10.3.2hh-1). For input ranges of 5 V/div and 10 V/div (Tables 10.3.2ii-1 and 10.3.2jj-1), the r.f. power amplifier is employed. Since the amplifier does not operate much below 500 kHz, the oscilloscope responses to frequencies up to 100 MHz are compared to the reference frequency of 50 kHz in two steps: first the oscilloscope responses are compared to the response at 500 kHz; then, the 500 kHz response is compared with the 50 kHz response. (See tables 10.3.2m-1 and 10.3.2n-1)

Part 1: DC - 200 kHz, for Channel 1

1. Connect the ac calibrator to Channel 1 of the oscilloscope as shown in figure 10.3.2a. The 10:1 attenuator should be connected directly to the Channel 1 input connector. Set the ac voltage calibrator to 50 kHz and 106.1 mV.

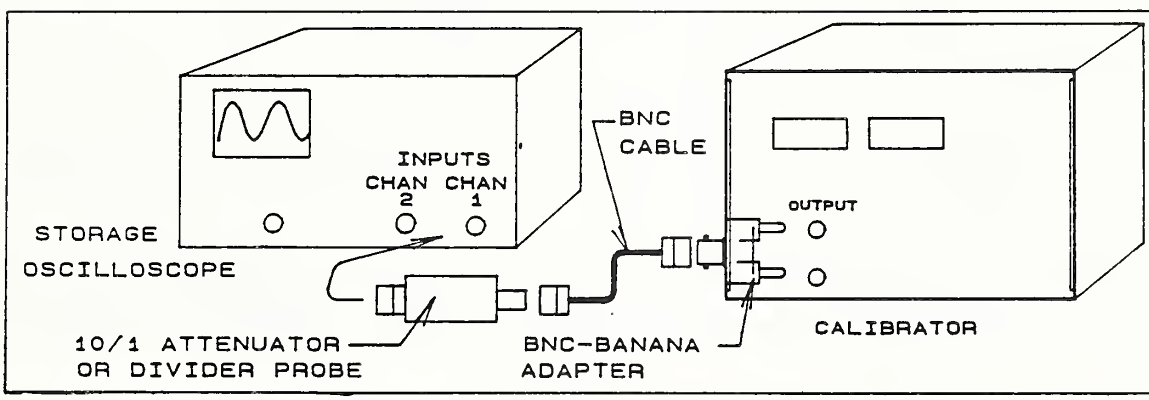


Figure 10.3.2a Test setup for measuring the frequency response from dc to 200 kHz. The 10:1 attenuator facilitates the use of larger calibrator voltages for the 5, 10, and 20 mV/div ranges. A 10:1 voltage divider probe, supplied by the oscilloscope manufacturer, is used instead of the attenuator for large calibrator voltages.

2. Set the Channel 1 range (deflection factor) of the storage oscilloscope to 5 mV/div, the sweep speed to 10 μs/div, and the input coupling to dc and 50 Ω OFF.

3. Set the cursors in the delta voltage mode to measure the peak-to-peak voltage .

4. Record the readout into table 10.3.2a-1.

5. Offset the cursor spacing an arbitrary amount, and then reposition the cursors as before. Record the new readout.

6. Repeat step 5 four more times, so that a total of 6 readings have been recorded.

7. After step 6, use the calculator to average the six readings ($A_v = V_r$) and to calculate the standard deviation, s. Using the value of ϵ_{ca} obtained from column 4, calculate the quantity ($\epsilon_{ca} + 0.8s = \epsilon_r$) and enter this quantity into column 5 (right-hand column).

8. Change the oscilloscope range to 10 mV/div and the ac voltage calibrator to 212.1 mV, as indicated in table 10.3.2a-1.

9. Repeat steps 3, 4, 5, 6, and 7.

10. Change the range to 20 mV/div and the voltage calibrator to 424 mV.

11. Repeat steps 3, 4, 5, 6, and 7.

12. Change the oscilloscope range to 50 mV/div and the voltage calibrator to 106.1 mV. Remove the 10:1 attenuator and connect the output of the calibrator <u>directly</u> to Channel 1 of the oscilloscope.

13. Repeat steps 3, 4, 5, 6, and 7.

14. Repeat steps 3, 4, 5, 6, and 7 for each of the remaining voltage ranges (and corresponding calibrator voltages) shown in table 10.3.2a-1.

15. Remove the NIST special attenuator and use the 10:1 voltage divider probe with the BNC tip adapter supplied by the manufacturer to connect the ac voltage calibrator to the oscilloscope under test. The input coupling to the oscilloscope should remain at dc and 50 Ω OFF.

16. Set the ac calibrator to 50 kHz and to 10.61 V output. Set the storage oscilloscope to an indicated range of 5V/div. Use the cursors in the delta mode to make 6 peak-to-peak measurements. Enter these values into table 10.3.21-1.

17. Compute the average ($A_v = V_r$), and the standard deviation, s. Compute ($\epsilon_r = \epsilon_{ca} + 0.8s$) for entry into the right-hand column.

18. Repeat steps 16 and 17 for the 10 V/div, 20 V/div and 50 V/div ranges, using the corresponding rms voltages shown in column 2 of table 10.3.2.1-1

19. Set the Fluke 5101B DC Calibrator to 0.0 mV dc, and connect this calibrator to Channel 1 of the oscilloscope as shown in figure 10.3.2b. The NIST special attenuator should be connected directly to the Channel 1 input connector. Set the oscilloscope range to 5 mV/div and position the sweep trace for exactly 0.0 mV vertical deflection.

20. Set the dc calibrator output to 150 mV dc and reverse its polarity several times. Note that the oscilloscope trace should be deflected vertically ±3 divisions.

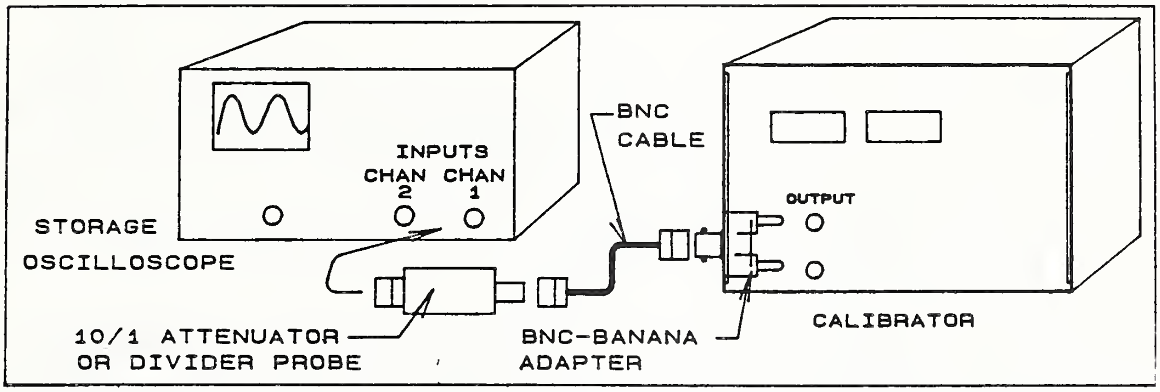


Figure 10.3.2b Test setup for measuring the dc voltage deflection sensitivity of the oscilloscope. The 10:1 attenuator facilitates the use of larger calibrator voltages for the 5, 10, and 20 mV/div ranges. A 10:1 voltage divider probe, supplied by the oscilloscope manufacturer, is used instead of the attenuator for large calibrator voltages.

21. Turn the delta voltage cursors on and adjust the spacing and offset so that the cursor lines coincide with the ± 150 mV horizontal traces caused by changing the calibrator's output polarity. Adjust the display intensity for best resolution.

22. Record the readout of the delta voltage into the 2nd column of table 10.3.2b-1.

23. Offset the cursor spacing an arbitrary amount, and then reposition the cursors as before. Record the new readout into the 2nd column of the table on the frequency row marked DC.

24. Repeat step 23 three more times, so that a total of 5 readings have been recorded. Use the calculator to obtain the average of these readings, Vo, and the standard deviation, s. Next enter the quantity (ϵ_{ca} + s = ϵ) into column 4, where ϵ_{ca} is the calibrator uncertainty listed in column 3.

25. Obtain from table 10.3.2a-1 the reference voltage, V_r, for the 5 mV/div range, and ϵ_r, the uncertainty in V_r. Compute (V_o-V_r) and enter in column 5 of table 10.3.2b-1. Then compute (ϵ + ϵ_r) and enter in column 6. Check to see that (V_o-V_r) is within the specification limits listed <u>above</u> the double line in the right hand column.

26. Change the oscilloscope range to 10 mV/div, and change the dc calibrator output to 300 mV, as indicated in the caption for table 10.3.2c-1.

27. Repeat steps 21 through 25 and enter the data in table 10.3.2c-1.

28. Refer to table 10.3.2d-1 and adjust the calibrator voltage and oscilloscope range as indicated in the caption. Repeat steps 21 through 25.

29. Remove the 10:1 attenuator and follow the same procedure (steps 21-25) for tables 10.3.2e-1 through 10.3.2k-1. At this point the first row (dc) of tables 10.3.2b-1 through 10.3.2k-1 should be filled with data.

30. Remove the 10:1 NIST special attenuator and use the 10:1 voltage divider probe with the BNC tip adapter to connect the dc calibrator to the oscilloscope. (See figure 10.3.2b).

31. Set the dc calibrator to 15 V dc and the oscilloscope to an indicated (scope readout) range of 5 V/div. Use the cursors in the delta voltage mode and make 5 measurements of the trace spacing, caused by reversing the calibrator polarity. Record these values in the first row of table 10.3.2m-1.

32. Average these values to obtain V_o and compute the standard deviation, s, and enter the quantity (ϵ_{ca} + s = ϵ) into column 4.

33. Obtain from table 10.3.21-1 the reference voltage V_r for the 5 V/div range and ϵ_r, the uncertainty in V_r. Compute (V_o-V_r) and enter into column 5 of table 10.3.2m-1. Compute ($\epsilon+\epsilon_r$) and enter into column 6. Check that (V_o-V_r) is within the specification limits shown in the right-hand column.

34. Repeat steps 31, 32, and 33 for the 10 V/div, 20 V/div and 50 V/div ranges (Tables 10.3.2n-1, 10.3.2o-1 and 10.3.2p-1), using the dc calibrator voltages shown. At this point the first row (dc) of tables 10.3.2m-1 through 10.3.2p-1 should be filled with data.

35. Disconnect the dc calibrator and connect the ac calibrator to the oscilloscope input, using the 10:1 NIST special attenuator. (See figure 10.3.2a) Set the oscilloscope range to 5 mV/div.

36. Set the ac calibrator frequency to 10 Hz, the amplitude of the ac calibrator output to 106.1 mV rms, and position the waveform for approximately ±3 divisions of deflection. Select the sweep speed to display 4 or more cycles.

37. Use the cursors in the delta voltage mode to measure the peak-to-peak voltage. Record the readout in the appropriate frequency row of table 10.3.2b-1. Offsetting the cursor spacing an arbitrary amount after each measurement, repeat this measurement four more times, so that 5 readings have been recorded in the table.

38. Calculate the average of these 5 readings, V_o, and the standard deviation, s. Enter the quantity (ϵ_{ca} + s = ϵ) in column 4, where ϵ_{ca} is the calibrator uncertainty listed in column 3.

39. Obtain from table 10.3.2a-1 the reference voltage V_r for the 5 mV/div range, and ϵ_r, the uncertainty in V_r. Compute V_o-V_r and enter in column 5, and compute $\epsilon+\epsilon_r$ and enter in column 6. Check to see that V_o-V_r is within the specification limits listed above the double line in the righthand column.

40. Repeat steps 37, 38, and 39 for each of the other calibrator frequencies: 100 Hz, 1 kHz, 10 kHz and 200 kHz.

41. Steps 35 through 40 described the procedure for acquiring data for table 10.3.2b-1. Follow the same procedure for tables 10.3.2c-1 through 10.3.2k-1, changing only the calibrator voltage and oscilloscope range, as indicated in the table captions. Also note that the 10:1 NIST special attenuator is not used for tables 10.3.2e-1 through 10.3.2k-1.

42. Use the 10:1 voltage divider probe with BNC tip adapter to connect the ac calibrator to the oscilloscope. (See figure 10.3.2a).

43. Set the ac calibrator to 10 Hz and 10.61 V rms, and the oscilloscope to an indicated range of 5V/div. Use the cursors in the delta voltage mode and make 5 measurements of the peak-to-peak voltage. Record these values in table 10.3.2m-1.

44. Average the values to obtain V_o and compute the standard deviation, s. Enter the quantity (ϵ_{ca} + s = ϵ) into column 4.

45. Obtain from table 10.3.2l-1, the reference voltage Vr for the 5V/div range and ϵ_r, the uncertainty in V_r. Compute (V_o-V_r) and enter into column 5 of table 10.3.2m-1 and compute ($\epsilon+\epsilon_r$) and enter into column 6. Check that (V_o-V_r) is within the specification limits listed in the righthand column.

46. Repeat steps 43, 44, and 45 for the other frequencies in table 10.3.2m-1.

47. Apply steps 43, 44, 45, and 46 to tables 10.3.2n-1, 10.3.2o-1 and 10.3.2p-1, using the information provided in the table captions and column headings.

Note: The last row of tables 10.3.2m-1 and 10.3.2n-1 is used to measure the response difference, ΔV, between 50 kHz and 500 kHz for the ranges (with probe) of 5 V/div and 10 V/div. The frequency 500 kHz serves as the reference for the 500 kHz to 100 MHz frequency range for p-p voltages larger than 5.5V. ΔV relates the oscilloscope/probe response over this latter frequency range to its response over the dc - 200 kHz range. ϵ_Δ is the uncertainty in ΔV. ΔV and ϵ_Δ are determined in the same way as (V_o -V_r) and (ϵ + ϵ_r) in tables 10.3.2m-1 and 10.3.2n-1. The frequency response at 10 Hz is omitted in these two tables.

Table 10.3.2a-1 Bandwidth - Channel 1 - without Probe. Calibrator Frequency: 50 kHz

Voltage Range	Calibrator Output (rms)	Measurement of Peak-to-Peak Voltage V_r	Calibrator Uncertainty ϵ_{ca}	Uncertainty in V_r. $\epsilon_r = \epsilon_{ca} + 0.8s$
5 mV /div	106.1 mV Use 10:1 attenuator	1)____ 4)____ 2)____ 5)____ 3)____ 6)____ Av)____ s)____	.021 mV	±____mV
10 mV /div	212.2 mV Use 10:1 attenuator	1)____ 4)____ 2)____ 5)____ 3)____ 6)____ Av)____ s)____	.044 mV	±____mV
20 mV /div	424 mV Use 10:1 attenuator	1)____ 4)____ 2)____ 5)____ 3)____ 6)____ Av)____ s)____	.074 mV	±____mV
50 mV /div	106.1 mV	1)____ 4)____ 2)____ 5)____ 3)____ 6)____ Av)____ s)____	0.21 mV	±____mV
100 mV /div	212.2 mV	1)____ 4)____ 2)____ 5)____ 3)____ 6)____ Av)____ s)____	0.44 mV	±____mV
200 mV /div	424 mV	1)____ 4)____ 2)____ 5)____ 3)____ 6)____ Av)____ s)____	0.74 mV	±____mV
500 mV /div	1.061 V	1)____ 4)____ 2)____ 5)____ 3)____ 6)____ Av)____ s)____	0.00164 V	±____ V

Table 10.3.2a-1 Bandwidth - Channel 1 - without Probe. Calibrator Frequency: 50 kHz - con't

Voltage Range	Calibrator Output (rms)	Measurement of Peak-to-Peak Voltage V_r	Calibrator Uncertainty ϵ_{ca}	Uncertainty in V_r. $\epsilon_r = \epsilon_{ca} + 0.8s$
1 V /div	2.122 V	1)______ 4)______ 2)______ 5)______ 3)______ 6)______ Av)______ s)______	0.00441 V	±______V
2 V /div	4.24 V	1)______ 4)______ 2)______ 5)______ 3)______ 6)______ Av)______ s)______	0.00741 V	±______V
5 V /div	10.61 V	1)______ 4)______ 2)______ 5)______ 3)______ 6)______ Av)______ s)______	0.0164 V	±______V

Table 10.3.2b-1 Bandwidth - Channel 1 - without Probe - 5 mV Range. Calibrator Output: 106.1 mV rms or 150 mV dc. Use 10:1 Attenuator

Freq.	Measurement p-p Volts V_o	Calibrator Uncertainty ϵ_{ca}	Uncertainty in V_o $\epsilon = \epsilon_{ca}+s$	Flatness V_o-V_r[1]	Uncertainty in V_o-V_r $\epsilon + \epsilon_r$	Specification Limits (P-P) Min.	Max.
DC	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.0029 mV	____mV	____mV	±____mV	-1.68mV -0.85mV	1.68 mV 0.85 mV
10 Hz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.0450 mV	____mV	____mV	±____mV	-1.68mV -0.85mV	1.68 mV 0.85 mV
100 Hz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.021 mV	____mV	____mV	±____mV	-1.68mV -0.85mV	1.68 mV 0.85 mV
1 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.021 mV	____mV	____mV	±____mV	-1.68mV -0.85mV	1.68 mV 0.85 mV
10 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.021 mV	____mV	____mV	±____mV	-1.68mV -.085mV	1.68 mV 0.85 mV
200 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.20 mV	____mV	____mV	±____mV	-1.68mV	1.68 mV

[1] See table 10.3.2a-1 for V_r and ϵ_r.

Table 10.3.2c-1 Bandwidth - Channel 1 - without Probe - 10 mV Range. Calibrator Output: 212.2 mV rms or 300 mV dc. Use 10:1 Attenuator

Freq.	Measurement p-p Volts V_o	Calibrator Uncertainty ϵ_{ca}	Uncertainty in V_o $\epsilon = \epsilon_{ca}+s$	Flatness V_o-V_r[1]	Uncertainty in V_o-V_r $\epsilon + \epsilon_r$	Specification Limits (P-P) Min.	Max.
DC	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.008 mV	____mV	____mV	±____mV	-3.36mV -1.70mV	3.36 mV 1.70 mV
10 Hz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.098 mV	____mV	____mV	±____mV	-3.36mV -1.70mV	3.36 mV 1.70 mV
100 Hz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.042 mV	____mV	____mV	±____mV	-3.36mV -1.70mV	3.36 mV 1.70 mV
1 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.042 mV	____mV	____mV	±____mV	-3.36mV -1.70mV	3.36 mV 1.70 mV
10 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.042 mV	____mV	____mV	±____mV	-3.36mV -.1.70V	3.36 mV 1.70 mV
200 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.46 mV	____mV	____mV	±____mV	-3.36mV	3.36 mV

[1] See table 10.3.2a-1 for V_r and ϵ_r.

Table 10.3.2d-1 Bandwidth - Channel 1 - without Probe - 20 mV Range. Calibrator Output: 424 mV rms or 600 mV dc. Use 10:1 Attenuator

Freq.	Measurement p-p Volts V_o	Calibrator Uncertainty ϵ_{ca}	Uncertainty in V_o $\epsilon = \epsilon_{ca}+s$	Flatness $V_o - V_r$[1]	Uncertainty in $V_o - V_r$ $\epsilon + \epsilon_r$	Specification Limits (P-P) Min.	Max.
DC	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.011 mV	____mV	____mV	±____mV	-6.7 mV -3.4 mV	6.7 mV 3.4 mV
10 Hz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.18 mV	____mV	____mV	±____mV	-6.7 mV -3.4 mV	6.7 mV 3.4 mV
100 Hz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.078 mV	____mV	____mV	±____mV	-6.7 mV -3.4 mV	6.7 mV 3.4 mV
1 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.078 mV	____mV	____mV	±____mV	-6.7 mV -3.4 mV	6.7 mV 3.4 mV
10 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.078 mV	____mV	____mV	±____mV	-6.7 mV -3.4 mV	6.7 mV 3.4 mV
200 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.84 mV	____mV	____mV	±____mV	-6.7 mV	6.7 mV

[1] See table 10.3.2a-1 for V_r and ϵ_r.

Table 10.3.2e-1 Bandwidth - Channel 1 - without Probe - 50 mV Range.
Calibrator Output: 106.1 mV rms or 150 mV dc.

Freq.	Measure-ment p-p Volts V_o	Calibrator Uncertainty ϵ_{ca}	Uncer-tainty in V_o $\epsilon = \epsilon_{ca}+s$	Flat-ness V_o-V_r[1]	Uncer-tainty in V_o-V_r $\epsilon + \epsilon_r$	Specification Limits (P-P) Min.	Max.
DC	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.029 mV	____mV	____mV	±____mV	-16.8mV -8.5 mV	16.8 mV 8.5 mV
10 Hz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.45 mV	____mV	____mV	±____mV	-16.8mV -8.5 mV	16.8 mV 8.5 mV
100 Hz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.21 mV	____mV	____mV	±____mV	-16.8 mV -8.5 mV	16.8 mV 8.5 mV
1 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.21 mV	____mV	____mV	±____mV	-16.8 mV -8.5 mV	16.8 mV 8.5 mV
10 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.21 mV	____mV	____mV	±____mV	-16.8 mV -8.5 mV	16.8 mV 8.5 mV
200 kHz	1)____ 3)____ 4)____ 5)____ Av____	1.97 mV	____mV	____mV	±____mV	-16.8 mV	16.8 mV

[1] See table 10.3.2a-1 for V_r and ϵ_r.

Table 10.3.2f-1 Bandwidth - Channel 1 - without Probe - 100 mV Range.
Calibrator Output: 212.2 mV rms or 300 mV dc.

Freq.	Measurement p-p Volts V_o	Calibrator Uncertainty ϵ_{ca}	Uncertainty in V_o $\epsilon = \epsilon_{ca}+s$	Flatness V_o-V_r[1]	Uncertainty in V_o-V_r $\epsilon + \epsilon_r$	Specification Limits (P-P) Min.	Max.
DC	1)___ 2)___ 3)___ 4)___ 5)___ Av___	0.08 mV	___ mV	___ mV	±___ mV	-33.6 mV -17.0 mV	33.6 mV 17.0 mV
10 Hz	1)___ 2)___ 3)___ 4)___ 5)___ Av___	0.98 mV	___ mV	___ mV	±___ mV	-33.6 mV -17.0 mV	33.6 mV 17.0 mV
100 Hz	1)___ 2)___ 3)___ 4)___ 5)___ Av___	0.42 mV	___ mV	___ mV	±___ mV	-33.6 mV -17.0 mV	33.6 mV 17.0 mV
1 kHz	1)___ 2)___ 3)___ 4)___ 5)___ Av___	0.42 mV	___ mV	___ mV	±___ mV	-33.6 mV -17.0 mV	33.6 mV 17.0 mV
10 kHz	1)___ 2)___ 3)___ 4)___ 5)___ Av___	0.42 mV	___ mV	___ mV	±___ mV	-33.6 mV -17.0 mV	33.6 mV 17.0 mV
200 kHz	1)___ 2)___ 3)___ 4)___ 5)___ Av___	4.6 mV	___ mV	___ mV	±___ mV	-33.6 mV	33.6 mV

[1] See table 10.3.2a-1 for V_r and ϵ_r.

Table 10.3.2g-1 Bandwidth - Channel 1 - without Probe - 200 mV Range.
Calibrator Output: 424 mV rms or 600 mV dc.

Freq.	Measurement p-p Volts V_o	Calibrator Uncertainty ϵ_{ca}	Uncertainty in V_o $\epsilon = \epsilon_{ca}+s$	Flatness V_o-V_r[1]	Uncertainty in V_o-V_r $\epsilon + \epsilon_r$	Specification Limits (P-P) Min.	Max.
DC	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.00011 V	____ V	____ V	±____ V	-0.067 V -0.034 V	0.067 V 0.034 V
10 Hz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.0018 V	____ V	____ V	±____ V	-0.067 V -0.034 V	0.067 V 0.34 V
100 Hz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.00078 V	____ V	____ V	±____ V	-0.067 V -0.034 V	0.067 V 0.034 V
1 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.00078 V	____ V	____ V	±____ V	-0.067 V -0.034 V	0.067 V 0.034 V
10 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.00078 V	____ V	____ V	±____ V	-0.067 V -0.034 V	0.067 V 0.034 V
200 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.0084 V	____ V	____ V	±____ V	-0.067 V	0.067 V

[1] See table 10.3.2a-1 for V_r and ϵ_r.

Table 10.3.2h-1 Bandwidth - Channel 1 - without Probe - 500 mV Range.
Calibrator Output: 1.061 V rms or 1.5 V dc.

Freq.	Measurement p-p Volts V_o	Calibrator Uncertainty ϵ_{ca}	Uncertainty in V_o $\epsilon = \epsilon_{ca}+s$	Flatness V_o-V_r[1]	Uncertainty in V_o-V_r $\epsilon + \epsilon_r$	Specification Limits (P-P) Min.	Max.
DC	1)___ 2)___ 3)___ 4)___ 5)___ Av___	0.0002 V	___V	___V	±___V	-0.168 V	0.168 V
						-0.085 V	0.085 V
10 Hz	1)___ 2)___ 3)___ 4)___ 5)___ Av___	0.0043 V	___V	___V	±___V	-0.168 V	0.168 V
						-0.085 V	0.085 V
100 Hz	1)___ 2)___ 3)___ 4)___ 5)___ Av___	0.0019 V	___V	___V	±___V	-0.168 V	0.168 V
						-0.085 V	0.085 V
1 kHz	1)___ 2)___ 3)___ 4)___ 5)___ Av___	0.0019 V	___V	___V	±___V	-0.168 V	0.168 V
						-0.085V	0.085 V
10 kHz	1)___ 2)___ 3)___ 4)___ 5)___ Av___	0.0019 V	___V	___V	±___V	-0.168 V	0.168 V
						-0.085 V	0.085 V
200 kHz	1)___ 2)___ 3)___ 4)___ 5)___ Av___	0.020 V	___V	___V	±___V	-0.168 V	0.168 V

[1] See table 10.3.2a-1 for V_r and ϵ_r.

Table. 10.3.2i-1 Bandwidth - Channel 1 - without Probe - 1 V Range.
Calibrator Output: 2.122 V rms or 3 V dc.

Freq.	Measurement p-p Volts V_o	Calibrator Uncertainty ϵ_{ca}	Uncertainty in V_o $\epsilon = \epsilon_{ca}+s$	Flatness V_o-V_r[1]	Uncertainty in V_o-V_r $\epsilon + \epsilon_r$	Specification Limits (P-P) Min.	Max.
DC	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.00071 V	____ V	____ V	±____ V	-0.336 V -0.170 V	0.336 V 0.170 V
10 Hz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.0098 V	____ V	____ V	±____ V	-0.336 V -0.170 V	0.336 V 0.170 V
100 Hz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.0042 V	____ V	____ V	±____ V	-0.336 V -0.170 V	0.336 V 0.170 V
1 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.0042 V	____ V	____ V	±____ V	-0.336V -0.170 V	0.336 V 0.170 V
10 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.0042 V	____ V	____ V	±____ V	-0.336 V -0.170 V	0.336 V 0.170 V
200 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.046 V	____ V	____ V	±____ V	-0.336V	0.336 V

[1] See table 10.3.2a-1 for V_r and ϵ_r.

Table 10.3.2j-1 Bandwidth - Channel 1 - without Probe - 2 V Range.
Calibrator Output: 4.24 V rms or 6 V dc

Freq.	Measurement p-p Volts V_o	Calibrator Uncertainty ϵ_{ca}	Uncertainty in V_o $\epsilon = \epsilon_{ca}+s$	Flatness V_o-V_r[1]	Uncertainty in V_o-V_r $\epsilon + \epsilon_r$	Specification Limits (P-P) Min.	Max.
DC	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.0010 V	____V	____V	±____V	-.67 V -.34 V	.67 V .34 V
10 Hz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.018 V	____V	____V	±____V	-.67 V -.34 V	.67 V .34 V
100 Hz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.0078 V	____V	____V	±____V	-.67 V -.34 V	.67 V .34 V
1 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.0078 V	____V	____V	±____V	-.67 V -.34 V	.67 V .34 V
10 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.0078 V	____V	____V	±____V	-.67 V -.34 V	.67 V .34 V
200 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.084 V	____V	____V	±____V	-.67 V	.67 V

[1] See table 10.3.2a-1 for V_r and ϵ_r.

Table 10.3.2k-1 Bandwidth - Channel 1 - without Probe - 5 V Range.
Calibrator Output: 10.61 V rms or 15 V dc

Freq.	Measurement p-p Volts V_o	Calibrator Uncertainty ϵ_{ca}	Uncertainty in V_o $\epsilon = \epsilon_{ca}+s$	Flatness V_o-V_r[1]	Uncertainty in V_o-V_r $\epsilon + \epsilon_r$	Specification Limits (P-P) Min.	Max.
DC	1)______ 2)______ 3)______ 4)______ 5)______ Av______	0.0019 V	______V	______V	±______V	-1.68 V -0.85 V	1.68 V 0.85 V
10 Hz	1)______ 2)______ 3)______ 4)______ 5)______ Av______	0.043 V	______V	______V	±______V	-1.68 V -0.85 V	1.68 V 0.85 V
100 Hz	1)______ 2)______ 3)______ 4)______ 5)______ Av______	0.019 V	______V	______V	±______V	-1.68 V -0.85 V	1.68 V 0.85 V
1 kHz	1)______ 2)______ 3)______ 4)______ 5)______ Av______	0.019 V	______V	______V	±______V	-1.68 V -0.85 V	1.68 V 0.85 V
10 kHz	1)______ 2)______ 3)______ 4)______ 5)______ Av______	0.019 V	______V	______V	±______V	-1.68 V -0.85 V	1.68 V 0.85 V
200 kHz	1)______ 2)______ 3)______ 4)______ 5)______ Av______	0.20 V	______V	______V	±______V	-1.68 V	1.68 V

[1] See table 10.3.2a-1 for V_r and ϵ_r.

Table 10.3.21-1 Bandwidth - Channel 1 - with Probe. Calibrator Frequency: 50 kHz

Voltage Range	Calibrator Output (rms)	Measurement of Peak-to-Peak Voltage V_r	Calibrator Uncertainty ϵ_{ca}	Uncertainty in V_r. $\epsilon_r = \epsilon_{ca} + 0.8s$
5 V /div	10.61 V	1)____ 4)____ 2)____ 5)____ 3)____ 6)____ Av)____ s)____	0.0164 V	±____V
10 V /div	21.22 V	1)____ 4)____ 2)____ 5)____ 3)____ 6)____ Av)____ s)____	0.0441 V	±____V
20 V /div	42.4 V	1)____ 4)____ 2)____ 5)____ 3)____ 6)____ Av)____ s)____	0.0741 V	±____V
50 V /div	106.1 V	1)____ 4)____ 2)____ 5)____ 3)____ 6)____ Av)____ s)____	0.164 V	±____V

Table 10.3.2m-1 Bandwidth - Channel 1 - with Probe - 5 V Range.
Calibrator Output: 10.61 V rms or 15 V dc

Freq.	Measurement p-p Volts V_o	Calibrator Uncertainty ϵ_{ca}	Uncertainty in V_o $\epsilon = \epsilon_{ca}+s$	Flatness V_o-V_r[1]	Uncertainty in V_o-V_r $\epsilon + \epsilon_r$	Specification Limits (P-P) Min.	Max.
DC	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.0019 V	____V	____V	±____V	-1.68 V	1.68 V
100 Hz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.019 V	____V	____V	±____V	-1.68 V	1.68 V
1 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.019 V	____V	____V	±____V	-1.68 V	1.68 V
10 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.019 V	____V	____V	±____V	-1.68 V	1.68 V
200 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.20 V	____V	____V	±____V	-1.68 V	1.68 V
500 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.20 V	____V	$\Delta V =$ ____V	$\epsilon_\Delta =$ ±____V	-1.68 V	1.68V

[1] See table 10.3.21-1 for V_r and ϵ_r.

Table 10.3.2n-1 Bandwidth - Channel 1 - with Probe - 10 V Range.
Calibrator Output: 21.2 V rms or 30 V dc

Freq.	Measurement p-p Volts V_o	Calibrator Uncertainty ϵ_{ca}	Uncertainty in V_o $\epsilon = \epsilon_{ca}+s$	Flatness V_o-V_r[1]	Uncertainty in V_o-V_r $\epsilon + \epsilon_r$	Specification Limits (P-P) Min.	Max.
DC	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.0070 V	____V	____V	±____V	-3.36 V	3.36 V
100 Hz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.042 V	____V	____V	±____V	-3.36 V	3.36 V
1 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.042 V	____V	____V	±____V	-3.36 V	3.36 V
10 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.042 V	____V	____V	±____V	-3.36 V	3.36 V
200 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.46 V	____V	____V	±____V	-3.36 V	3.36 V
500 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.46 V	____V	ΔV = ____V	ϵ_Δ = ±____V	-3.36 V	3.36 V

[1] See table 10.3.21-1 for V_r and ϵ_r.

Table 10.3.2o-1 Bandwidth - Channel 1 - with Probe - 20 V Range.
Calibrator Output: 42.4 rms or 60 V dc

Freq.	Measurement p-p Volts V_o	Calibrator Uncertainty ϵ_{ca}	Uncertainty in V_o $\epsilon = \epsilon_{ca}+s$	Flatness V_o-V_r[1]	Uncertainty in V_o-V_r $\epsilon + \epsilon_r$	Specification Limits (P-P) Min.	Max.
DC	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.010 V	____ V	____ V	±____ V	-6.7 V	6.7 V
10 Hz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.18 V	____ V	____ V	±____ V	-6.7 V	6.7 V
100 Hz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.077 V	____ V	____ V	±____ V	-6.7 V	6.7 V
1 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.077 V	____ V	____ V	±____ V	-6.7 V	6.7 V
10 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.077 V	____ V	____ V	±____ V	-6.7 V	6.7 V
200 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.84 V	____ V	____ V	±____ V	-6.7 V	6.7 V

[1] See table 10.3.21-1 for V_r and ϵ_r.

Table 10.3.2p-1 Bandwidth - Channel 1 - with Probe - 50 V Range.
Calibrator Output: 106.1 rms or 150 V dc

Freq.	Measurement p-p Volts V_o	Calibrator Uncertainty ϵ_{ca}	Uncertainty in V_o $\epsilon = \epsilon_{ca}+s$	Flatness $V_o - V_r$[1]	Uncertainty in $V_o - V_r$ $\epsilon + \epsilon_r$	Specification Limits (P-P) Min.	Max.
DC	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.019 V	____V	____V	±____V	-16.8 V	16.8 V
10 Hz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.43 V	____V	____V	±____V	-16.8 V	16.8 V
100 Hz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.19 V	____V	____V	±____V	-16.8 V	16.8 V
1 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.19 V	____V	____V	±____V	-16.8 V	16.8 V
10 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.19 V	____V	____V	±____V	-16.8 V	16.8 V
200 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	2.0 V	____V	____V	±____V	-16.8 V	16.8 V

[1] See table 10.3.21-1 for V_r and ϵ_r.

Part 2: 50 kHz - 100 MHz, for Channel 1

1. Connect the sine-wave generator output to Channel 1 with the 36" cable as shown in figure 10.3.2c. The input coupling of the storage oscilloscope should be set to dc and 50Ω ON (i.e., 50Ω input impedance).

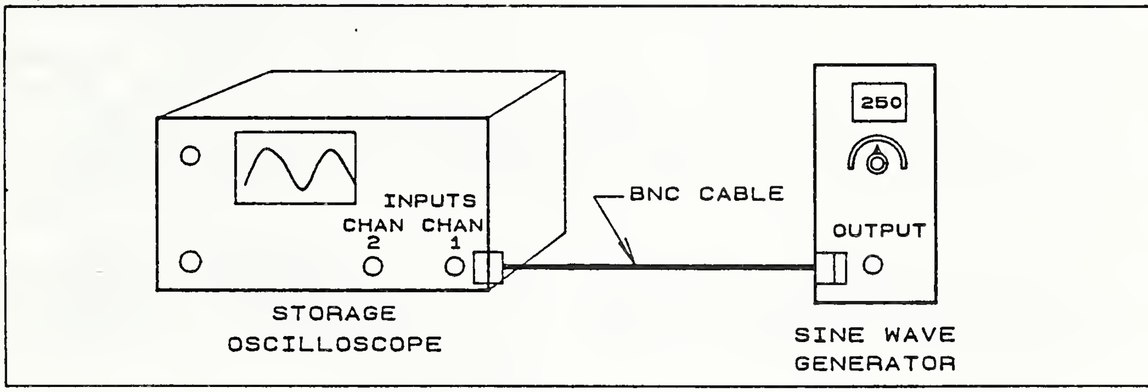


Figure 10.3.2c Test setup for measuring the frequency response from 50 kHz to 100 MHz for input voltages up to 5.5 V p-p

2. As indicated in the table caption of table 10.3.2aa-1, set the oscilloscope range to 5 mV/div. Set the generator frequency to 50 kHz, and adjust the generator amplitude for a peak-to-peak deflection of 6 divisions (30 mV). After this adjustment has been made, be very careful not to disturb this amplitude setting of the sine-wave generator until all measurements have been made for this table.

3. Use the cursors in the delta voltage mode and make 5 measurements of the peak-to-peak amplitude. Record these values in table 10.3.2aa-1. Average these values to obtain V_r, and compute the standard deviation, s. Enter this quantity into column 4.

4. Without disturbing the amplitude setting, change the frequency to 1 MHz. Use the cursors to make 5 measurements of the peak-to-peak amplitude. Record these values into the table. Average these values to obtain V_o, and compute s. Using the sine-wave generator uncertainty listed in column 3, compute ($\epsilon_g + s = \epsilon$), the uncertainty in V_o, and enter into column 4.

5. Using the value of V_r, computed in row 1, calculate (V_o-V_r) and enter into column 5. Check to see that (V_o-V_r) is within the specification limits listed in the right hand column.

6. Repeat steps 4 and 5 for 10 MHz and 100 MHz.

7. Steps 2 through 6 establish the aberrations or flatness (strictly speaking, lack of flatness) over the 50 kHz to 100 MHz frequency band for the 5 mV range. Use the procedure outlined by these steps to determine

the flatness of the ranges called out in tables 10.3.2bb-1 through 10.3.2hh-1. Note: For the last table (1 V range) it will be necessary to use less than 6 divisions peak-to-peak deflection, since the maximum available p-p voltage from the sine-wave generator is about 5.5 V.

NOTE: The test setup shown in figure 10.3.2d is used to measure the frequency response of the oscilloscope/probe over the frequency range of 500 kHz to 100 MHz. tables 10.3.ii-1 and 10.3.2jj-1 are used to compute the flatness over this range, using 500 kHz, as the reference. However, since 50 kHz is the reference frequency for the entire bandwidth (dc - 100 MHz), it is necessary to measure the difference between the oscilloscope/probe's response at 500 kHz and its response at 50 kHz. This difference is measured using the relatively accurate Fluke 5200A Calibrator. The quantity is represented by "ΔV" in the last row of tables 10.3.2m-1 and 10.3.2n-1, and should be recorded in the first row of tables 10.3.2ii-1 and 10.3.2jj-1. Here, ΔV is used as a correction to the 500 kHz reference voltage, V_o. The uncertainty, ϵ_Δ, was obtained from tables 10.3.2m-1 and 10.3.2n-1, along with ΔV.

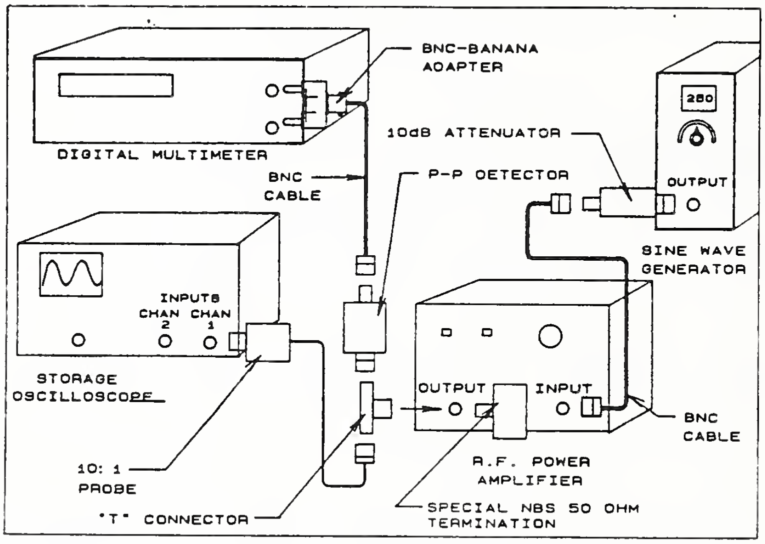


Figure 10.3.2d Test setup for measuring the frequency response of the oscilloscope/probe combination for frequencies between 500 kHz - 100 MHz. The P-P Detector is used to monitor the output voltage of the amplifier, which is applied to the probe.

8. Refer to figure 10.3.2d but do not apply power to the sine-wave generator and RF amplifier. Set the amplitude multiplier to the X.01 position and the output amplitude to an extreme counterclockwise position (minimum signal level). CAUTION: To prevent burn out of the P-P Detector from overvoltage, always disconnect the input cable to the amplifier before changing positions of the amplitude multiplier.

9. Set the oscilloscope range to 5 V/div and turn the generator and amplifier ON. Set the input coupling to dc and 50 Ω OFF. Set the frequency to 500 kHz and adjust the rf signal amplitude for a peak-to-peak oscilloscope deflection of 6 divisions (0 ± 3 divisions). Record on a scratch pad the DVM reading of the P-P Detector dc output voltage. Designate this voltage as V_d.

10. Use the cursors in the delta voltage mode and make 5 measurements of the peak-to-peak sine wave voltage. Compute V_o (the average of these readings, Av.) and the standard deviation, s. Compute V_r, the reference voltage referred to the oscilloscope/probe's response at 50 kHz, and ϵ_r, the uncertainty in V_r. Record these results in table 10.3.2ii-1.

11. Change the frequency to 1 MHz and adjust the rf signal amplitude uncalibrated for a DVM reading of $V_d \pm 0.06$ V. The oscilloscope deflection should again be very close to 6 divisions p-p. Make the indicated measurements, using cursors and compute V_o, s, ϵ_g+s, V_o-V_r and $\epsilon + \epsilon_r$. where the values of V_r and ϵ_r are brought down from row 1. Record these results in the appropriate frequency row of table 10.3.2ii-1.

12. Repeat step 11 for the 10 MHz and 100 MHz frequencies.

13. Refer to table 10.3.2jj-1. Repeat steps 9, 10, 11, and 12 for the 10 V/div range of the storage oscilloscope.

Table 10.3.2aa-1 Bandwidth - Channel 1 - without Probe 5 mV Range - Sine-Wave Generator Output: 30 mV p-p

Freq.	Measurement p-p Volts V_r		Uncertainty in V_r $\epsilon_r = s$				
50 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____		____V				
Freq.	**Measurement p-p Volts V_o**	**Sine Wave Generator Uncertainty ϵ_g**	**Uncertainty in V_o $\epsilon = \epsilon_g + s$**	**Flatness $V_o - V_r$**	**Uncertainty in $V_o - V_r$ $\epsilon + \epsilon_r$**	**Specification Limits (P-P) Min.**	**Max.**
1 MHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.30 mV	____mV	____mV	±____mV	-1.68 mV	1.68 mV
10 MHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.30 mV	____mV	____mV	±____mV	-1.68 mV	1.68 mV
100 MHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.30 mV	____mV	____mV	±____mV	-8.79 mV	1.68 mV

Table 10.3.2bb-1 Bandwidth - Channel 1 - without Probe 10 mV Range - Sine-Wave Generator Output: 60 mV p-p

Freq.	Measurement p-p Volts V_r		Uncertainty in V_r $\epsilon_r = s$				
50 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____		____ V				
Freq.	**Measurement p-p Volts V_o**	**Sine Wave Generator Uncertainty ϵ_g**	**Uncertainty in V_o $\epsilon = \epsilon_g + s$**	**Flatness V_o-V_r**	**Uncertainty in V_o-V_r $\epsilon + \epsilon_r$**	**Specification Limits (P-P) Min.**	**Max.**
1 MHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.60 mV	____ mV	____ mV	±____ mV	-3.36 mV	3.36 mV
10 MHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.60 mV	____ mV	____ mV	±____ mV	-3.36 mV	3.36 mV
100 MHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.60 mV	____ mV	____ mV	±____ mV	-17.6 mV	3.36 mV

Table 10.3.2cc-1 Bandwidth - Channel 1 - without Probe 20 mV Range - Sine-Wave Generator Output: 120 mV p-p

Freq.	Measurement p-p Volts V_r		Uncertainty in V_r $\epsilon_r = s$				
50 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____		____V				
Freq.	**Measurement p-p Volts V_o**	**Sine Wave Generator Uncertainty ϵ_g**	**Uncertainty in V_o $\epsilon = \epsilon_g + s$**	**Flatness V_o-V_r**	**Uncertainty in V_o-V_r $\epsilon + \epsilon_r$**	**Specification Limits (P-P) Min.**	**Max.**
1 MHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	1.20 mV	____mV	____mV	±____mV	-6.7 mV	6.7 mV
10 MHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	1.20 mV	____mV	____mV	±____mV	-6.7 mV	6.7 mV
100 MHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	1.20 mV	____mV	____mV	±____mV	-35.2 mV	6.7 mV

Table 10.3.2dd-1 Bandwidth - Channel 1 - without Probe 50 mV Range - Sine-Wave Generator Output: 300 mV p-p

Freq.	Measurement p-p Volts V_r		Uncertainty in V_r $\epsilon_r = s$				
50 kHz	1)___ 2)___ 3)___ 4)___ 5)___ Av___		___V				
Freq.	**Measurement p-p Volts V_o**	**Sine Wave Generator Uncertainty ϵ_g**	**Uncertainty in V_o $\epsilon = \epsilon_g + s$**	**Flatness $V_o - V_r$**	**Uncertainty in $V_o - V_r$ $\epsilon + \epsilon_r$**	**Specification Limits (P-P) Min.**	**Max.**
1 MHz	1)___ 2)___ 3)___ 4)___ 5)___ Av___	3.00 mV	___mV	___mV	±___mV	-16.8 mV	16.8 mV
10 MHz	1)___ 2)___ 3)___ 4)___ 5)___ Av___	3.00 mV	___mV	___mV	±___mV	-16.8 mV	16.8 mV
100 MHz	1)___ 2)___ 3)___ 4)___ 5)___ Av___	3.00 mV	___mV	___mV	±___mV	-87.9 mV	16.8 mV

Table 10.3.2ee-1 Bandwidth - Channel 1 - without Probe 100 mV Range - Sine-Wave Generator Output: 600 mV p-p

Freq.	Measurement p-p Volts V_r		Uncertainty in V_r $\epsilon_r = s$				
50 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____		____ V				
Freq.	Measurement p-p Volts V_o	Sine Wave Generator Uncertainty ϵ_g	Uncertainty in V_o $\epsilon = \epsilon_g + s$	Flatness $V_o - V_r$	Uncertainty in $V_o - V_r$ $\epsilon + \epsilon_r$	Specification Limits (P-P) Min.	Max.
1 MHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	6.0 mV	____ mV	____ mV	±____ mV	-33.6 mV	33.6 mV
10 MHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	6.0 mV	____ mV	____ mV	±____ mV	-33.6 mV	33.6 mV
100 MHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	6.0 mV	____ mV	____ mV	±____ mV	-176 mV	33.6 mV

Table 10.3.2ff-1 Bandwidth - Channel 1 - without Probe 200 mV Range - Sine-Wave Generator Output: 1.2 V p-p

Freq.	Measurement p-p Volts V_r		Uncertainty in V_r $\epsilon_r = s$				
50 kHz	1) ______ 2) ______ 3) ______ 4) ______ 5) ______ Av ______		______ V				
Freq.	Measurement p-p Volts V_o	Sine Wave Generator Uncertainty ϵ_g	Uncertainty in V_o $\epsilon = \epsilon_g + s$	Flatness $V_o - V_r$	Uncertainty in $V_o - V_r$ $\epsilon + \epsilon_r$	Specification Limits (P-P) Min.	Max.
1 MHz	1) ______ 2) ______ 3) ______ 4) ______ 5) ______ Av ______	0.012 V	______ mV	______ mV	± ______ mV	-0.067 V	0.067 V
10 MHz	1) ______ 2) ______ 3) ______ 4) ______ 5) ______ Av ______	0.012 V	______ mV	______ mV	± ______ mV	-0.067 V	0.067 V
100 MHz	1) ______ 2) ______ 3) ______ 4) ______ 5) ______ Av ______	0.012 V	______ mV	______ mV	± ______ mV	-0.352 V	0.067 V

Table 10.3.2gg-1 Bandwidth - Channel 1 - without Probe 500 mV Range - Sine-Wave Generator Output: 3 V p-p

Freq.	Measurement p-p Volts V_r		Uncertainty in V_r $\epsilon_r = s$
50 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____		____V

Freq.	Measurement p-p Volts V_o	Sine Wave Generator Uncertainty ϵ_g	Uncertainty in V_o $\epsilon = \epsilon_g + s$	Flatness $V_o - V_r$	Uncertainty in $V_o - V_r$ $\epsilon + \epsilon_r$	Specification Limits (P-P) Min.	Max.
1 MHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.030 V	____mV	____mV	±____mV	-0.168 V	0.168 V
10 MHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.030 V	____mV	____mV	±____mV	-0.168 V	0.168 V
100 MHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.030 V	____mV	____mV	±____mV	-0.879 V	0.168 V

Table 10.3.2hh-1 Bandwidth - Channel 1 - without Probe 1 V Range - Sine-Wave Generator Output: 5.5 V p-p

Freq.	Measurement p-p Volts V_r		Uncertainty in V_r $\epsilon_r = s$				
50 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____		____V				
Freq.	**Measurement p-p Volts V_o**	**Sine Wave Generator Uncertainty ϵ_g**	**Uncertainty in V_o $\epsilon = \epsilon_g + s$**	**Flatness V_o-V_r**	**Uncertainty in V_o-V_r $\epsilon + \epsilon_r$**	**Specification Limits (P-P) Min.**	**Max.**
1 MHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.055 V	____mV	____mV	±____mV	-0.31 V	0.31 V
10 MHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.055 V	____mV	____mV	±____mV	-0.31 V	0.31 V
100 MHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.055 V	____mV	____mV	±____mV	-1.61 V	0.31 V

Table 10.3.2ii-1 Bandwidth - Channel 1 - with Probe 5 V Range - Sine-Wave Generator Output: 30 V p-p

Freq.	Measurement p-p Volts V_o	Flatness at 500 kHz (ΔV)	$V_r = V_o - \Delta V$	Uncertainty in ΔV (ϵ_Δ)	Uncertainty in V_o (s)	Uncertainty in V_r = $\epsilon_r = \epsilon_\Delta + s$
500 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	____				

Freq.	Measurement p-p Volts V_o	Sine Wave Generator Uncertainty ϵ_g	Uncertainty in V_o $\epsilon = \epsilon_g + s$	Flatness $V_o - V_r$	Uncertainty in $V_o - V_r$ $\epsilon + \epsilon_r$	Specification Limits (P-P) Min.	Max.
1 MHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.60 V	____V	____V	±____V	-1.68 V	1.68 V
10 MHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.60 V	____V	____V	±____V	-1.68 V	1.68 V
100 MHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.60 V	____V	____V	±____V	-8.79 V	1.68 V

Table 10.3.2jj-1 Bandwidth - Channel 1 - with Probe 10 V Range - Sine-Wave Generator Output: 60 V p-p

Freq.	Measurement p-p Volts V_o	Flatness at 500 kHz (ΔV)	$V_r = V_o - \Delta V$	Uncertainty in ΔV (ϵ_Δ)	Uncertainty in V_o (s)	Uncertainty in V_r = $\epsilon_r = \epsilon_\Delta + s$
500 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	______				

Freq.	Measurement p-p Volts V_o	Sine Wave Generator Uncertainty ϵ_g	Uncertainty in V_o $\epsilon = \epsilon_g + s$	Flatness $V_o - V_r$	Uncertainty in $V_o - V_r$ $\epsilon + \epsilon_r$	Specification Limits (P-P) Min.	Max.
1 MHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	1.20 V	____ V	____ V	±____ V	-3.36 V	3.36 V
10 MHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	1.20 V	____ V	____ V	±____ V	-3.36 V	3.36 V
100 MHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	1.20 V	____ V	____ V	±____ V	-17.6 V	3.36 V

Part 3: DC - 200 kHz, for Channel 2

14. Connect the ac calibrator to Channel 2 of the oscilloscope as shown in figure 10.3.2e. The 10:1 attenuator should be connected directly to the Channel 2 input connector. Set the ac voltage calibrator to 50 kHz and 106.1 mV.

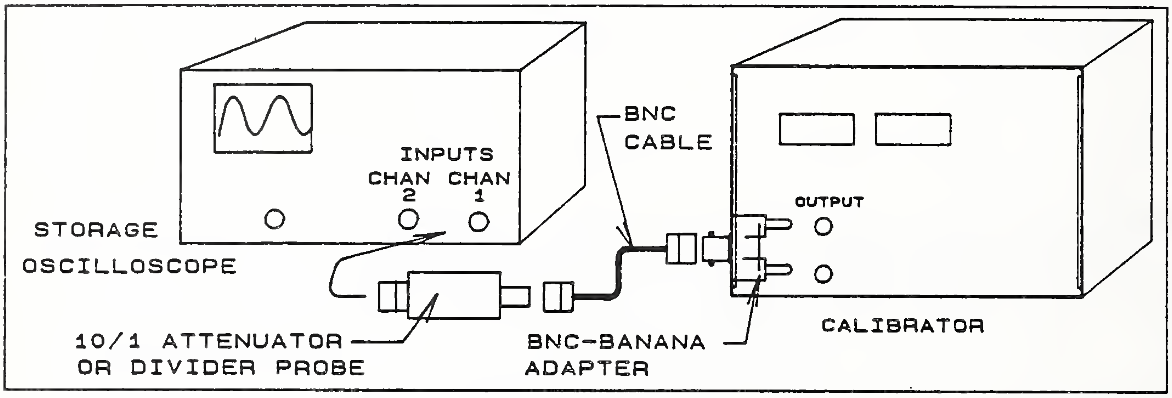


Figure 10.3.2e Test setup for measuring the frequency response from dc to 200 kHz. The 10:1 attenuator facilitates the use of larger calibrator voltages for the 5, 10, and 20 mV/div ranges. A 10:1 voltage divider probe, supplied by the oscilloscope manufacturer, is used instead of the attenuator for large calibrator voltages.

15. Set the Channel 2 range (deflection factor) of the storage oscilloscope to 5 mV/div, the sweep speed to 10 μs/div, and the input coupling to dc and 50 Ω OFF.

16. Set the cursors in the delta voltage mode to measure the peak-to-peak voltage.

17. Record the readout into table 10.3.2a-2.

18. Offset the cursor spacing an arbitrary amount, and then reposition the cursors as before. Record the new readout.

19. Repeat step 5 four more times, so that a total of 6 readings have been recorded.

20. After step 6, use the calculator to average the six readings ($A_v = V_r$) and to calculate the standard deviation, s. Using the value of ϵ_{ca} obtained from column 4, calculate the quantity ($\epsilon_{ca} + 0.8s = \epsilon_r$) and enter this quantity into column 5 (righthand column).

21. Change the oscilloscope range to 10 mV/div and the ac voltage calibrator to 212.1 mV, as indicated in table 10.3.2a-2.

22. Repeat steps 3, 4, 5, 6, and 7.

23. Change the range to 20 mV/div and the voltage calibrator to 424 mV.

24. Repeat steps 3, 4, 5, 6, and 7.

25. Change the oscilloscope range to 50 mV/div and the voltage calibrator to 106.1 mV. Remove the 10:1 attenuator and connect the output of the calibrator <u>directly</u> to Channel 2 of the oscilloscope.

26. Repeat steps 3, 4, 5, 6, and 7.

27. Repeat steps 3, 4, 5, 6, and 7 for each of the remaining voltage ranges (and corresponding calibrator voltages) shown in table 10.3.2a-2.

28. Remove the NIST special attenuator and use the 10:1 voltage divider probe with the BNC tip adapter supplied by the manufacturer to connect the ac voltage calibrator to the oscilloscope under test. The input coupling to the oscilloscope should remain at dc and 50 Ω OFF.

29. Set the ac calibrator to 50 kHz and to 10.61 V output. Set the storage oscilloscope to an indicated range of 5V/div. Use the cursors in the delta mode to make 6 peak-to-peak measurements. Enter these values into table 10.3.21-2.

30. Compute the average $(A_v - V_r)$, and the standard deviation, s. Compute $(\epsilon_r - \epsilon_{ca} + 0.8s)$ for entry into the righthand column.

31. Repeat steps 16 and 17 for the 10 V/div, 20 V/div and 50 V/div ranges, using the corresponding rms voltages shown in column 2 of table 10.3.2.1-1

32. Set the Fluke 5101B Calibrator to 0.0 mV dc, and connect this calibrator to Channel 2 of the oscilloscope as shown in figure 10.3.2f. The NIST special attenuator should be connected directly to the Channel 2 input connector. Set the oscilloscope range to 5 mV/div and position the sweep trace for exactly 0.0 mV vertical deflection.

33. Set the dc calibrator output to 150 mV dc and reverse its polarity several times. Note that the oscilloscope trace should be deflected vertically ±3 divisions.

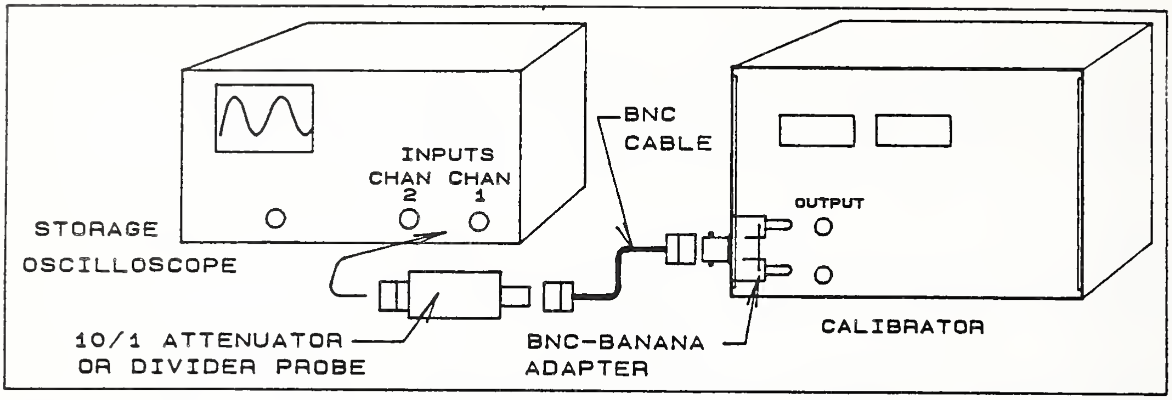


Figure 10.3.2f Test setup for measuring the dc voltage deflection sensitivity of the oscilloscope. The 10:1 attenuator facilitates the use of larger calibrator voltages for the 5, 10, and 20 mV/div ranges. A 10:1 voltage divider probe, supplied by the oscilloscope manufacturer, is used instead of the attenuator for large calibrator voltages.

34. Turn the delta voltage cursors on and adjust the spacing and offset so that the cursor lines coincide with the ± 150 mV horizontal traces caused by changing the calibrator's output polarity. Adjust the display intensity for best resolution.

35. Record the readout of the delta voltage into the 2nd column of table 10.3.2b-2.

36. Offset the cursor spacing an arbitrary amount, and then reposition the cursors as before. Record the new readout into the 2nd column of the table on the frequency row marked DC.

37. Repeat step 23 three more times, so that a total of 5 readings have been recorded. Use the calculator to obtain the average of these readings, Vo, and the standard deviation, s. Next enter the quantity (ϵ_{ca} + s = ϵ) into column 4, where ϵ_{ca} is the calibrator uncertainty listed in column 3.

38. Obtain from table 10.3.2a-2 the reference voltage, V_r, for the 5 mV/div range, and ϵ_r, the uncertainty in V_r. Compute $(V_o - V_r)$ and enter in column 5 of table 10.3.2b-2. Then compute $(\epsilon + \epsilon_r)$ and enter in column 6. Check to see that $(V_o - V_r)$ is within the specification limits listed <u>above</u> the double line in the right hand column.

39. Change the oscilloscope range to 10 mV/div, and change the dc calibrator output to 300 mV, as indicated in the caption for table 10.3.2c-2.

40. Repeat steps 21 through 25 and enter the data in table 10.3.2c-2.

41. Refer to table 10.3.2d-2 and adjust the calibrator voltage and oscilloscope range as indicated in the caption. Repeat steps 21 through 25.

42. Remove the 10:1 attenuator and follow the same procedure (steps 21-25) for tables 10.3.2e-2 through 10.3.2k-2. At this point the first row (dc) of tables 10.3.2b-2 through 10.3.2k-2 should be filled with data.

43. Remove the 10:1 NIST special attenuator and use the 10:1 voltage divider probe with the BNC tip adapter to connect the dc calibrator to the oscilloscope. (See figure 10.3.2f).

44. Set the dc calibrator to 15 V dc and the oscilloscope to an indicated (scope readout) range of 5 V/div. Use the cursors in the delta voltage mode and make 5 measurements of the trace spacing, caused by reversing the calibrator polarity. Record these values in the first row of table 10.3.2m-2.

45. Average these values to obtain V_o and compute the standard deviation, s, and enter the quantity (ϵ_{ca} + s = ϵ) into column 4.

46. Obtain from table 10.3.21-2 the reference voltage V_r for the 5 V/div range and ϵ_r, the uncertainty in V_r. Compute (V_o-V_r) and enter into column 5 of table 10.3.2m-2. Compute (ϵ+ϵ_r) and enter into column 6. Check that (V_o-V_r) is within the specification limits shown in the righthand column.

47. Repeat steps 31, 32, and 33 for the 10 V/div, 20 V/div and 50 V/div ranges (Tables 10.3.2n-2, 10.3.2o-2 and 10.3.2p-2), using the dc calibrator voltages shown. At this point the first row (dc) of tables 10.3.2m-2 through 10.3.2p-2 should be filled with data.

48. Disconnect the dc calibrator and connect the ac calibrator to the oscilloscope input, using the 10:1 NIST special attenuator. (See figure 10.3.2e) Set the oscilloscope range to 5 mV/div.

49. Set the ac calibrator frequency to 10 Hz, the amplitude of the ac calibrator output to 106.1 mV rms, and position the waveform for approximately ±3 divisions of deflection. Select the sweep speed to display 4 or more cycles.

50. Use the cursors in the delta voltage mode to measure the peak-to-peak voltage. Record the readout in the appropriate frequency row of table 10.3.2b-2. Offsetting the cursor spacing an arbitrary amount after each measurement, repeat this measurement four more times, so that 5 readings have been recorded in the table.

51. Calculate the average of these 5 readings, V_o, and the standard deviation, s. Enter the quantity (ϵ_{ca} + s = ϵ) in column 4, where ϵ_{ca} is the calibrator uncertainty listed in column 3.

52. Obtain from table 10.3.2a-2 the reference voltage V_r for the 5 mV/div range, and ϵ_r, the uncertainty in V_r. Compute V_o-V_r and enter in column 5, and compute ϵ+ϵ_r and enter in column 6. Check to see that V_o-V_r is within the specification limits listed <u>above</u> the double line in the righthand column.

53. Repeat steps 37, 38, and 39 for each of the other calibrator frequencies: 100 Hz, 1 kHz, 10 kHz and 200 kHz.

54. Steps 35 through 40 described the procedure for acquiring data for table 10.3.2b-2. Follow the same procedure for tables 10.3.2c-2 through 10.3.2k-2, changing only the calibrator voltage and oscilloscope range, as indicated in the table captions. Also note that the 10:1 NIST special attenuator is <u>not</u> used for tables 10.3.2e-2 through 10.3.2k-2.

55. Use the 10:1 voltage divider probe with BNC tip adapter to connect the ac calibrator to the oscilloscope. (See figure 10.3.2e).

56. Set the ac calibrator to 10 Hz and 10.61 V rms, and the oscilloscope to an indicated range of 5 V/div. Use the cursors in the delta voltage mode and make 5 measurements of the peak-to-peak voltage. Record these values in table 10.3.2m-2.

57. Average the values to obtain V_o and compute the standard deviation, s. Enter the quantity (ϵ_{ca} + s = ϵ) into column 4.

58. Obtain from table 10.3.21-2, the reference voltage Vr for the 5V/div range and ϵ_r, the uncertainty in V_r. Compute (V_o-V_r) and enter into column 5 of table 10.3.2m-2 and compute (ϵ+ϵ_r) and enter into column 6. Check that (V_o-V_r) is within the specification limits listed in the righthand column.

59. Repeat steps 43, 44, and 45 for the other frequencies in table 10.3.2m-2.

60. Apply steps 43, 44, 45, and 46 to tables 10.3.2n-2, 10.3.2o-2 and 10.3.2p-2, using the information provided in the table captions and column headings.

Note: The last row of tables 10.3.2m-2 and 10.3.2n-2 is used to measure the response difference, ΔV, between 50 kHz and 500 kHz for the ranges (with probe) of 5 V/div and 10 V/div. The frequency 500 kHz serves as the reference for the 500 kHz to 100 MHz frequency range for p-p voltages larger than 5.5V. ΔV relates the oscilloscope/probe response over this latter frequency range to its response over the dc - 200 kHz range. ϵ_Δ is the uncertainty in ΔV. ΔV and ϵ_Δ are determined in the same way as (V_o -V_r) and (ϵ + ϵ_r) in tables 10.3.2m-2 and 10.3.2n-1. The frequency response at 10 Hz is omitted in these two tables.

Table 10.3.2a-2 Bandwidth - Channel 2 - without Probe. Calibrator Frequency: 50 kHz

Voltage Range	Calibrator Output (rms)	Measurement of Peak-to-Peak Voltage V_r	Calibrator Uncertainty ϵ_{ca}	Uncertainty in V_r. $\epsilon_r = \epsilon_{ca} + 0.8s$
5 mV /div	106.1 mV Use 10:1 attenuator	1)_____ 4)_____ 2)_____ 5)_____ 3)_____ 6)_____ Av)_____ s)_____		±_____mV
10 V /div	212.2 mV Use 10:1 attenuator	1)_____ 4)_____ 2)_____ 5)_____ 3)_____ 6)_____ Av)_____ s)_____		±_____mV
20 mV /div	424 mV Use 10:1 attenuator	1)_____ 4)_____ 2)_____ 5)_____ 3)_____ 6)_____ Av)_____ s)_____		±_____mV
50 mV /div	106.1 mV	1)_____ 4)_____ 2)_____ 5)_____ 3)_____ 6)_____ Av)_____ s)_____		±_____mV
100 mV /div	212.2 mV	1)_____ 4)_____ 2)_____ 5)_____ 3)_____ 6)_____ Av)_____ s)_____		±_____mV
200 mV /div	424 mV	1)_____ 4)_____ 2)_____ 5)_____ 3)_____ 6)_____ Av)_____ s)_____		±_____mV
500 mV /div	1.061 V	1)_____ 4)_____ 2)_____ 5)_____ 3)_____ 6)_____ Av)_____ s)_____		±_____mV

Table 10.3.2a-2 Bandwidth - Channel 2 - without Probe. Calibrator Frequency: 50 kHz - con't

Voltage Range	Calibrator Output (rms)	Measurement of Peak-to-Peak Voltage V_r	Calibrator Uncertainty ϵ_{ca}	Uncertainty in V_r. $\epsilon_r = \epsilon_{ca} + 0.8s$
1 V /div	2.122 V	1)____ 4)____ 2)____ 5)____ 3)____ 6)____ Av)____ s)____		±____V
2 V /div	4.24 V	1)____ 4)____ 2)____ 5)____ 3)____ 6)____ Av)____ s)____		±____V
5 V /div	10.61 V	1)____ 4)____ 2)____ 5)____ 3)____ 6)____ Av)____ s)____		±____V

Table 10.3.2b-2 Bandwidth - Channel 2 - without Probe - 5 mV Range. Calibrator Output: 106.1 mV rms or 150 mV dc. Use 10:1 Attenuator

Freq.	Measurement p-p Volts V_o	Calibrator Uncertainty ϵ_{ca}	Uncertainty in V_o $\epsilon = \epsilon_{ca}+s$	Flatness $V_o - V_r$[1]	Uncertainty in $V_o - V_r$ $\epsilon + \epsilon_r$	Specification Limits (P-P) Min.	Max.
DC	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.0029 mV	____mV	____mV	±____mV	-1.68 mV -0.85 mV	1.68 mV 0.85 mV
10 Hz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.045 mV	____mV	____mV	±____mV	-1.68 mV -0.85 mV	1.68 mV 0.85 mV
100 Hz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.021 mV	____mV	____mV	±____mV	-1.68 mV -0.85 mV	1.68 mV 0.85 mV
1 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.021 mV	____mV	____mV	±____mV	-1.68 mV -0.85 mV	1.68 mV 0.85 mV
10 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.021 mV	____mV	____mV	±____mV	-1.68 mV -0.85 mV	1.68 mV 0.85 mV
200 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.20 mV	____mV	____mV	±____mV	-1.68 mV	1.68 mV

[1] See table 10.3.2a-2 for V_r and ϵ_r.

Table 10.3.2c-2 Bandwidth - Channel 2 - without Probe - 10 mV Range. Calibrator Output: 212.2 mV rms or 300 mV dc. Use 10:1 Attenuator

Freq.	Measurement p-p Volts V_o	Calibrator Uncertainty ϵ_{ca}	Uncertainty in V_o $\epsilon = \epsilon_{ca}+s$	Flatness V_o-V_r[1]	Uncertainty in V_o-V_r $\epsilon + \epsilon_r$	Specification Limits (P-P) Min.	Max.
DC	1)___ 2)___ 3)___ 4)___ 5)___ Av___	0.008 mV	___mV	___mV	±___mV	-3.36 mV -1.70 mV	3.36 mV 1.70 mV
10 Hz	1)___ 2)___ 3)___ 4)___ 5)___ Av___	0.098 mV	___mV	___mV	±___mV	-3.36 mV -1.70 mV	3.36 mV 1.70 mV
100 Hz	1)___ 2)___ 3)___ 4)___ 5)___ Av___	0.042 mV	___mV	___mV	±___mV	-3.36 mV -1.70 mV	3.36 mV 1.70 mV
1 kHz	1)___ 2)___ 3)___ 4)___ 5)___ Av___	0.042 mV	___mV	___mV	±___mV	-3.36 mV -1.70 mV	3.36 mV 1.70 mV
10 kHz	1)___ 2)___ 3)___ 4)___ 5)___ Av___	0.042 mV	___mV	___mV	±___mV	-3.36 mV -1.70 mV	3.36 mV 1.70 mV
200 kHz	1)___ 2)___ 3)___ 4)___ 5)___ Av___	0.46 mV	___mV	___mV	±___mV	-3.36 mV	3.36 mV

[1] See table 10.3.2a-2 for V_r and ϵ_r.

Table 10.3.2d-2 Bandwidth - Channel 2 - without Probe - 20 mV Range. Calibrator Output: 424 mV rms or 600 mV dc. Use 10:1 Attenuator

Freq.	Measurement p-p Volts V_o	Calibrator Uncertainty ϵ_{ca}	Uncertainty in V_o $\epsilon = \epsilon_{ca}+s$	Flatness $V_o - V_r$[1]	Uncertainty in $V_o - V_r$ $\epsilon + \epsilon_r$	Specification Limits (P-P) Min.	Max.
DC	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.011 mV	____mV	____mV	±____mV	-6.7 mV -3.4 mV	6.7 mV 3.4 mV
10 Hz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.18 mV	____mV	____mV	±____mV	-6.7 mV -3.4 mV	6.7 mV 3.4 mV
100 Hz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.078 mV	____mV	____mV	±____mV	-6.7 mV -3.4 mV	6.7 mV 3.4 mV
1 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.078 mV	____mV	____mV	±____mV	-6.7 mV -3.4 mV	6.7 mV 3.4 mV
10 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.078 mV	____mV	____mV	±____mV	-6.7 mV -3.4 mV	6.7 mV 3.4 mV
200 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.84 mV	____mV	____mV	±____mV	-6.7 mV	6.7 mV

[1] See table 10.3.2a-2 for V_r and ϵ_r.

Table 10.3.2e-2 Bandwidth - Channel 2 - without Probe - 50 mV Range.
Calibrator Output: 106.1 mV rms or 150 mV dc.

Freq.	Measurement p-p Volts V_o	Calibrator Uncertainty ϵ_{ca}	Uncertainty in V_o $\epsilon = \epsilon_{ca}+s$	Flatness V_o-V_r[1]	Uncertainty in V_o-V_r $\epsilon + \epsilon_r$	Specification Limits (P-P) Min.	Max.
DC	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.029 mV	____mV	____mV	±____mV	-16.8 mV -8.5 mV	16.8 mV 8.5 mV
10 Hz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.45 mV	____mV	____mV	±____mV	-16.8 mV -8.5 mV	16.8 mV 8.5 mV
100 Hz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.21 mV	____mV	____mV	±____mV	-16.8 mV -8.5 mV	16.8 mV 8.5 mV
1 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.21 mV	____mV	____mV	±____mV	-16.8 mV -8.5 mV	16.8 mV 8.5 mV
10 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.21 mV	____mV	____mV	±____mV	-16.8 mV -8.5 mV	16.8 mV 8.5 mV
200 kHz	1)____ 3)____ 4)____ 5)____ Av____	1.97 mV	____mV	____mV	±____mV	-16.8 mV	16.8 mV

[1] See table 10.3.2a-2 for V_r and ϵ_r.

Table 10.3.2f-2 Bandwidth - Channel 2 - without Probe - 100 mV Range.
Calibrator Output: 212.2 mV rms or 300 mV dc.

Freq.	Measurement p-p Volts V_o	Calibrator Uncertainty ϵ_{ca}	Uncertainty in V_o $\epsilon = \epsilon_{ca}+s$	Flatness $V_o - V_r$[1]	Uncertainty in $V_o - V_r$ $\epsilon + \epsilon_r$	Specification Limits (P-P) Min.	Max.
DC	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.08 mV	____mV	____mV	±____mV	-33.6 mV -17.0 mV	33.6 mV 17.0 mV
10 Hz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.98 mV	____mV	____mV	±____mV	-33.6 mV -17.0 mV	33.6 mV 17.0 mV
100 Hz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.42 mV	____mV	____mV	±____mV	-33.6 mV -17.0 mV	33.6 mV 17.0 mV
1 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.42 mV	____mV	____mV	±____mV	-33.6 mV -17.0 mV	33.6 mV 17.0 mV
10 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.42 mV	____mV	____mV	±____mV	-33.6 mV -17.0 mV	33.6 mV 17.0 mV
200 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	4.6 mV	____mV	____mV	±____mV	-33.6 mV	33.6 mV

[1] See table 10.3.2a-2 for V_r and ϵ_r.

Table 10.3.2g-2 Bandwidth - Channel 2 - without Probe - 200 mV Range.
Calibrator Output: 424 mV rms or 600 mV dc.

Freq.	Measurement p-p Volts V_o	Calibrator Uncertainty ϵ_{ca}	Uncertainty in V_o $\epsilon = \epsilon_{ca}+s$	Flatness V_o-V_r[1]	Uncertainty in V_o-V_r $\epsilon + \epsilon_r$	Specification Limits (P-P) Min.	Max.
DC	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.00011 V	____ V	____ V	±____ V	-0.067 V -0.034 V	0.067 V 0.034 V
10 Hz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.0018 V	____ V	____ V	±____ V	-0.067 V -0.034 V	0.067 V -.034 V
100 Hz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.0078 V	____ V	____ V	±____ V	-0.067 V -0.034 V	0.067 V 0.034 V
1 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.0078 V	____ V	____ V	±____ V	-0.067 V -0.034 V	0.067 V 0.034 V
10 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.00078 V	____ V	____ V	±____ V	-0.067 V -0.034 V	0.067 V 0.034 V
200 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.0084 V	____ V	____ V	±____ V	-0.067 V	0.067 V

[1] See table 10.3.2a-2 for V_r and ϵ_r.

Table 10.3.2h-2 Bandwidth - Channel 2 - without Probe - 500 mV Range.
Calibrator Output: 1.061 V rms or 1.5 V dc.

Freq.	Measurement p-p Volts V_o	Calibrator Uncertainty ϵ_{ca}	Uncertainty in V_o $\epsilon = \epsilon_{ca}+s$	Flatness V_o-V_r[1]	Uncertainty in V_o-V_r $\epsilon + \epsilon_r$	Specification Limits (P-P) Min.	Max.
DC	1)___ 2)___ 3)___ 4)___ 5)___ Av___	0.0002 V	___V	___V	±___V	-0.168 V -0.085 V	0.168 V 0.085 V
10 Hz	1)___ 2)___ 3)___ 4)___ 5)___ Av___	0.0043 V	___V	___V	±___V	-0.168 V -0.085 V	0.168 V 0.085 V
100 Hz	1)___ 2)___ 3)___ 4)___ 5)___ Av___	0.0019 V	___V	___V	±___V	-0.168 V -0.085 V	0.168 V 0.085 V
1 kHz	1)___ 2)___ 3)___ 4)___ 5)___ Av___	0.0019 V	___V	___V	±___V	-0.168 V -0.085V	0.168 V 0.085 V
10 kHz	1)___ 2)___ 3)___ 4)___ 5)___ Av___	0.0019 V	___V	___V	±___V	-0.168 V -0.085 V	0.168 V 0.085 V
200 kHz	1)___ 2)___ 3)___ 4)___ 5)___ Av___	0.020 V	___V	___V	±___V	-0.168 V	0.168 V

[1] See table 10.3.2a-2 for V_r and ϵ_r.

Table 10.3.2i-2 Bandwidth - Channel 2 - without Probe - 1 V Range.
Calibrator Output: 2.122 V rms or 3 V dc.

Freq.	Measurement p-p Volts V_o	Calibrator Uncertainty ϵ_{ca}	Uncertainty in V_o $\epsilon = \epsilon_{ca}+s$	Flatness V_o-V_r[1]	Uncertainty in V_o-V_r $\epsilon + \epsilon_r$	Specification Limits (P-P) Min.	Max.
DC	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.00071 V	____V	____V	±____V	-0.336 V -0.170 V	0.336 V 0.170 V
10 Hz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.0098 V	____V	____V	±____V	-0.336 V -0.170 V	0.336 V 0.170 V
100 Hz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.0042 V	____V	____V	±____V	-0.336 V -0.170 V	0.336 V 0.170 V
1 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.0042 V	____V	____V	±____V	-0.336 V -0.170 V	0.336 V 0.170 V
10 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.0042 V	____V	____V	±____V	-0.336 V -0.170 V	0.336 V 0.170 V
200 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.046 V	____V	____V	±____V	-0.336 V	0.336 V

[1] See table 10.3.2a-2 for V_r and ϵ_r.

Table 10.3.2j-2 Bandwidth - Channel 2 - without Probe - 2 V Range.
Calibrator Output: 4.24 V rms or 6 V dc

Freq.	Measurement p-p Volts V_o	Calibrator Uncertainty ϵ_{ca}	Uncertainty in V_o $\epsilon = \epsilon_{ca}+s$	Flatness $V_o - V_r$[1]	Uncertainty in $V_o - V_r$ $\epsilon + \epsilon_r$	Specification Limits (P-P) Min.	Max.
DC	1)___ 2)___ 3)___ 4)___ 5)___ Av___	0.0010 V	___V	___V	±___V	-0.67 V -0.34 V	0.67 V 0.34 V
10 Hz	1)___ 2)___ 3)___ 4)___ 5)___ Av___	0.018 V	___V	___V	±___V	-0.67 V -0.34 V	0.67 V 0.34 V
100 Hz	1)___ 2)___ 3)___ 4)___ 5)___ Av___	0.0078 V	___V	___V	±___V	-0.67 V -0.34 V	0.67 V 0.34 V
1 kHz	1)___ 2)___ 3)___ 4)___ 5)___ Av___	0.0078 V	___V	___V	±___V	-0.67 V -0.34 V	0.67 V 0.34 V
10 kHz	1)___ 2)___ 3)___ 4)___ 5)___ Av___	0.0078 V	___V	___V	±___V	-0.67 V -0.34 V	0.67 V 0.34 V
200 kHz	1)___ 2)___ 3)___ 4)___ 5)___ Av___	0.084 V	___V	___V	±___V	-0.67 V	0.67 V

[1] See table 10.3.2a-2 for V_r and ϵ_r.

Table 10.3.2k-2 Bandwidth - Channel 2 - without Probe - 5 V Range.
Calibrator Output: 10.61 V rms or 15 V dc

Freq.	Measurement p-p Volts V_o	Calibrator Uncertainty ϵ_{ca}	Uncertainty in V_o $\epsilon = \epsilon_{ca}+s$	Flatness $V_o - V_r$[1]	Uncertainty in $V_o - V_r$ $\epsilon + \epsilon_r$	Specification Limits (P-P) Min.	Max.
DC	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.0019 V	____V	____V	±____V	-1.68 V -0.85 V	1.68 V 0.85 V
10 Hz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.043 V	____V	____V	±____V	-1.68 V -0.85 V	1.68 V 0.85 V
100 Hz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.019 V	____V	____V	±____V	-1.68 V -0.85 V	1.68 V 0.85 V
1 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.019 V	____V	____V	±____V	-1.68 V -0.85 V	1.68 V 0.85 V
10 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.019 V	____V	____V	±____V	-1.68 V -0.85 V	1.68 V 0.85 V
200 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.20 V	____V	____V	±____V	-1.68 V	1.68 V

[1] See table 10.3.2a-2 for V_r and ϵ_r.

Table 10.3.21-2 Bandwidth - Channel 2 - with Probe. Calibrator Frequency: 50 kHz

Voltage Range	Calibrator Output (rms)	Measurement of Peak-to-Peak Voltage V_r	Calibrator Uncertainty ϵ_{ca}	Uncertainty in V_r. $\epsilon_r = \epsilon_{ca} + 0.8s$
5 V /div	10.61 V	1)____ 4)____ 2)____ 5)____ 3)____ 6)____ Av)____ s)____	±0.0030 V	±____V
10 V /div	21.22 V	1)____ 4)____ 2)____ 5)____ 3)____ 6)____ Av)____ s)____	±0.0055 V	±____V
20 V /div	42.4 V	1)____ 4)____ 2)____ 5)____ 3)____ 6)____ Av)____ s)____	±0.015 V	±____V
50 V /div	106.1 V	1)____ 4)____ 2)____ 5)____ 3)____ 6)____ Av)____ s)____	±0.030 V	±____V

Table 10.3.2m-2 Bandwidth - Channel 2 - with Probe - 5 V Range.
Calibrator Output: 10.61 V rms or 15 V dc

Freq.	Measurement p-p Volts V_o	Calibrator Uncertainty ϵ_{ca}	Uncertainty in V_o $\epsilon = \epsilon_{ca}+s$	Flatness V_o-V_r[1]	Uncertainty in V_o-V_r $\epsilon + \epsilon_r$	Specification Limits (P-P) Min.	Max.
DC	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.0019 V	____V	____V	±____V	-1.68 V	1.68 V
100 Hz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.019 V	____V	____V	±____V	-1.68 V	1.68 V
1 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.019 V	____V	____V	±____V	-1.68 V	1.68 V
10 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.019 V	____V	____V	±____V	-1.68 V	1.68 V
200 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.20 V	____V	____V	±____V	-1.68 V	1.68 V
500 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.20 V	____V	Δ V = ____V	ϵ_Δ = ±____V	-1.68 V	1.68 V

[1] See table 10.3.21-2 for V_r and ϵ_r.

Table 10.3.2n-2 Bandwidth - Channel 2 - with Probe - 10 V Range.
Calibrator Output: 21.2 V rms or 30 V dc

Freq.	Measurement p-p Volts V_o	Calibrator Uncertainty ϵ_{ca}	Uncertainty in V_o $\epsilon = \epsilon_{ca}+s$	Flatness $V_o - V_r$[1]	Uncertainty in $V_o - V_r$ $\epsilon + \epsilon_r$	Specification Limits (P-P) Min.	Max.
DC	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.0070 V	____V	____V	±____V	-3.36 V	3.36 V
100 Hz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.042 V	____V	____V	±____V	-3.36 V	3.36 V
1 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.042 V	____V	____V	±____V	-3.36 V	3.36 V
10 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.042 V	____V	____V	±____V	-3.36 V	3.36 V
200 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.46 V	____V	____V	±____V	-3.36 V	3.36 V
500 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.46 V	____V	Δ = ____V	ϵ_Δ = ±____V	-3.36 V	3.36 V

[1] See table 10.3.21-2 for V_r and ϵ_r.

Table 10.3.2o-2 Bandwidth - Channel 2 - with Probe - 20 V Range.
Calibrator Output: 42.4 rms or 60 V dc

Freq.	Measurement p-p Volts V_o	Calibrator Uncertainty ϵ_{ca}	Uncertainty in V_o $\epsilon = \epsilon_{ca}+s$	Flatness V_o-V_r[1]	Uncertainty in V_o-V_r $\epsilon + \epsilon_r$	Specification Limits (P-P) Min.	Max.
DC	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.010 V	____ V	____ V	±____ V	-6.7 V	6.7 V
10 Hz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.18 V	____ V	____ V	±____ V	-6.7 V	6.7 V
100 Hz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.077 V	____ V	____ V	±____ V	-6.7 V	6.7 V
1 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.077 V	____ V	____ V	±____ V	-6.7 V	6.7 V
10 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.077 V	____ V	____ V	±____ V	-6.7 V	6.7 V
200 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.84 V	____ V	____ V	±____ V	-6.7 V	6.7 V

[1] See table 10.3.21-2 for V_r and ϵ_r.

Table 10.3.2p-2 Bandwidth - Channel 2 - with Probe - 50 V Range.
Calibrator Output: 106.1 rms or 150 V dc

Freq.	Measurement p-p Volts V_o	Calibrator Uncertainty ϵ_{ca}	Uncertainty in V_o $\epsilon = \epsilon_{ca}+s$	Flatness V_o-V_r[1]	Uncertainty in V_o-V_r $\epsilon + \epsilon_r$	Specification Limits (P-P) Min.	Max.
DC	1)___ 2)___ 3)___ 4)___ 5)___ Av___	0.019 V	___ V	___ V	±___ V	-16.8 V	16.8 V
10 Hz	1)___ 2)___ 3)___ 4)___ 5)___ Av___	0.43 V	___ V	___ V	±___ V	-16.8 V	16.8 V
100 Hz	1)___ 2)___ 3)___ 4)___ 5)___ Av___	0.19 V	___ V	___ V	±___ V	-16.8 V	16.8 V
1 kHz	1)___ 2)___ 3)___ 4)___ 5)___ Av___	0.19 V	___ V	___ V	±___ V	-16.8 V	16.8 V
10 kHz	1)___ 2)___ 3)___ 4)___ 5)___ Av___	0.19 V	___ V	___ V	±___ V	-16.8 V	16.8 V
200 kHz	1)___ 2)___ 3)___ 4)___ 5)___ Av___	2.0 V	___ V	___ V	±___ V	-16.8 V	16.8 V

[1] See table 10.3.21-2 for V_r and ϵ_r.

Part 4: 50 kHz - 100 MHz, for Channel 2

1. Connect the sine-wave generator output to Channel 2 with the 36" cable as shown in figure 10.3.2g. The input coupling of the storage oscilloscope should be set to dc and 50Ω ON (i.e., 50Ω input impedance).

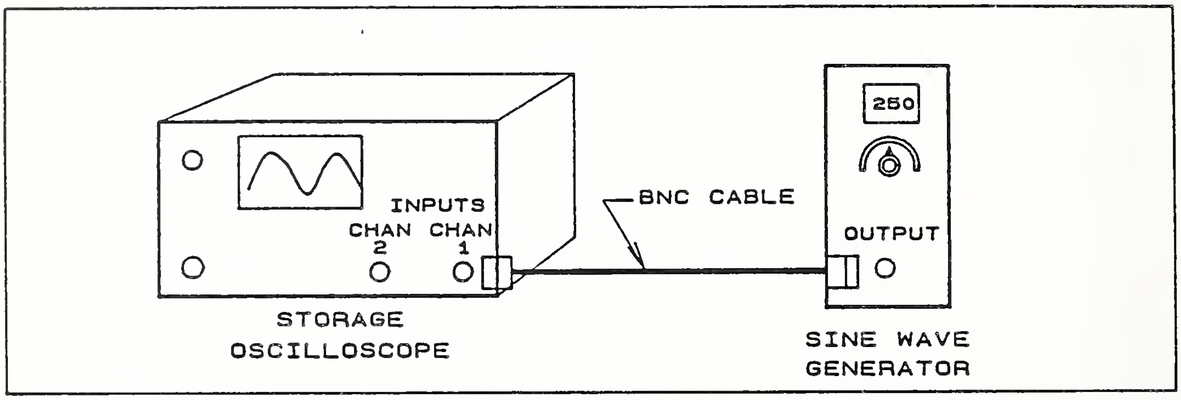


Figure 10.3.2g Test setup for measuring the frequency response from 50 kHz to 100 MHz for input voltages up to 5.5 V p-p

2. As indicated in the table caption of table 10.3.2aa-2, set the oscilloscope range to 5 mV/div. Set the generator frequency to 50 kHz, and adjust the generator amplitude for a peak-to-peak deflection of 6 divisions (30 mV). After this adjustment has been made, be very careful not to disturb this amplitude setting of the sine-wave generator until all measurements have been made for this table.

3. Use the cursors in the delta voltage mode and make 5 measurements of the peak-to-peak amplitude. Record these values in table 10.3.2aa-2. Average these values to obtain V_r, and compute the standard deviation, s. Enter this quantity into column 4.

4. Without disturbing the amplitude setting, change the frequency to 1 MHz. Use the cursors to make 5 measurements of the peak-to-peak amplitude. Record these values into the table. Average these values to obtain V_o, and compute s. Using the sine-wave generator uncertainty listed in column 3, compute ($\epsilon_g + s = \epsilon$), the uncertainty in V_o, and enter into column 4.

5. Using the value of V_r, computed in row 1, calculate (V_o-V_r) and enter into column 5. Check to see that (V_o-V_r) is within the specification limits listed in the right hand column.

6. Repeat steps 4 and 5 for 10 MHz and 100 MHz.

7. Steps 2 through 6 establish the aberrations or flatness (strictly speaking, lack of flatness) over the 50 kHz to 100 MHz frequency band for the 5 mV range. Use the procedure outlined by these steps to determine

the flatness of the ranges called out in tables 10.3.2bb-2 through 10.3.2hh-2. Note: For the last table (1 V range) it will be necessary to use less than 6 divisions peak-to-peak deflection, since the maximum available p-p voltage from the sine-wave generator is about 5.5 V.

NOTE: The test setup shown in figure 10.3.2h is used to measure the frequency response of the oscilloscope/probe over the frequency range of 500 kHz to 100 MHz. tables 10.3.ii-2 and 10.3.2jj-2 are used to compute the flatness over this range, using 500 kHz, as the reference. However, since 50 kHz is the reference frequency for the entire bandwidth (dc - 100 MHz), it is necessary to measure the difference between the oscilloscope/probe's response at 500 kHz and its response at 50 kHz. This difference is measured using the relatively accurate Fluke 5200A Calibrator. The quantity is represented by "ΔV" in the last row of tables 10.3.2m-2 and 10.3.2n-2, and should be recorded in the first row of tables 10.3.2ii-2 and 10.3.2jj-2. Here, ΔV is used as a correction to the 500 kHz reference voltage, V_o. The uncertainty, ϵ_Δ, was obtained from tables 10.3.2m-2 and 10.3.2n-2, along with ΔV.

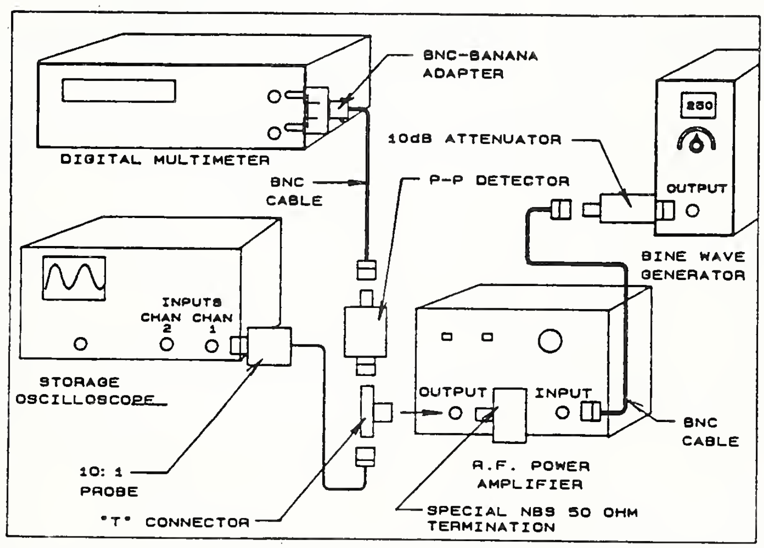


Figure 10.3.2h Test setup for measuring the frequency response of the oscilloscope/probe combination for frequencies between 500 kHz - 100 MHz. The P-P Detector is used to monitor the output voltage of the amplifier, which is applied to the probe.

8. Refer to figure 10.3.2h but do not apply power to the sine-wave generator and RF amplifier. Set the amplitude multiplier to the X.01 position and the output amplitude to an extreme counterclockwise position (minimum signal level). CAUTION: To prevent burn out of the P-P Detector from overvoltage, always disconnect the input cable to the amplifier before changing positions of the amplitude multiplier.

9. Set the oscilloscope range to 5 V/cm and turn the generator and amplifier ON. Set the frequency to 500 kHz and adjust the rf signal amplitude for a peak-to-peak oscilloscope deflection of 6 divisions (0 ± 3 divisions). Record on a scratch pad the DVM reading of the P-P Detector dc output voltage. Designate this voltage as V_d.

10. Use the cursors in the delta voltage mode and make 5 measurements of the peak-to-peak sine wave voltage. Compute V_o (the average of these readings, Av.) and the standard deviation, s. Compute V_r, the reference voltage referred to the oscilloscope/probe's response at 50 kHz, and ϵ_r, the uncertainty in V_r. Record these results in table 10.3.2ii-2.

11. Change the frequency to 1 MHz and adjust the rf signal amplitude uncalibrated for a DVM reading of $V_d \pm 0.06$ V. The oscilloscope deflection should again be very close to 6 divisions p-p. Make the indicated measurements, using cursors and compute V_o, s, ϵ_g+s, V_o-V_r and $\epsilon + \epsilon_r$. where the values of V_r and ϵ_r are brought down from row 1. Record these results in the appropriate frequency row of table 10.3.2ii-1.

12. Repeat step 11 for the 10 MHz and 100 MHz frequencies.

13. Refer to table 10.3.2jj-2. Repeat steps 9, 10, 11, and 12 for the 10 V/div range of the storage oscilloscope.

Table 10.3.2aa-2 Bandwidth - Channel 2 - without Probe 5 mV Range - Sine-Wave Generator Output: 30 mV p-p

Freq.	Measurement p-p Volts V_r		Uncertainty in V_r $\epsilon_r = s$
50 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____		____V

Freq.	Measurement p-p Volts V_o	Sine Wave Generator Uncertainty ϵ_g	Uncertainty in V_o $\epsilon = \epsilon_g + s$	Flatness $V_o - V_r$	Uncertainty in $V_o - V_r$ $\epsilon + \epsilon_r$	Specification Limits (P-P) Min.	Max.
1 MHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.30 mV	____mV	____mV	±____mV	-1.68 mV	1.68 mV
10 MHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.30 mV	____mV	____mV	±____mV	-1.68 mV	1.68 mV
100 MHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.30 mV	____mV	____mV	±____mV	-1.68 mV	1.68 mV

Table 10.3.2bb-2 Bandwidth - Channel 2 - without Probe 10 mV Range - Sine-Wave Generator Output: 60 mV p-p

Freq.	Measurement p-p Volts V_r		Uncertainty in V_r $\epsilon_r = s$
50 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____		____V

Freq.	Measurement p-p Volts V_o	Sine Wave Generator Uncertainty ϵ_g	Uncertainty in V_o $\epsilon = \epsilon_g + s$	Flatness $V_o - V_r$	Uncertainty in $V_o - V_r$ $\epsilon + \epsilon_r$	Specification Limits (P-P) Min.	Specification Limits (P-P) Max.
1 MHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.60 mV	____mV	____mV	±____mV	-3.36 mV	3.36 mV
10 MHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.60 mV	____mV	____mV	±____mV	-3.36 mV	3.36 mV
100 MHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.60 mV	____mV	____mV	±____mV	-3.36 mV	3.36 mV

Table 10.3.2cc-2 Bandwidth - Channel 2 - without Probe 20 mV Range - Sine-Wave Generator Output: 120 mV p-p

Freq.	Measurement p-p Volts V_r		Uncertainty in V_r $\epsilon_r = s$				
50 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____		____V				
Freq.	Measurement p-p Volts V_o	Sine Wave Generator Uncertainty ϵ_g	Uncertainty in V_o $\epsilon = \epsilon_g + s$	Flatness $V_o - V_r$	Uncertainty in $V_o - V_r$ $\epsilon + \epsilon_r$	Specification Limits (P-P) Min.	Max.
1 MHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	1.20 mV	____mV	____mV	±____mV	-6.7 mV	6.7 mV
10 MHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	1.20 mV	____mV	____mV	±____mV	-6.7 mV	6.7 mV
100 MHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	1.20 mV	____mV	____mV	±____mV	-6.7 mV	6.7 mV

Table 10.3.2dd-2 Bandwidth - Channel 2 - without Probe 50 mV Range - Sine-Wave Generator Output: 300 mV p-p

Freq.	Measurement p-p Volts V_r		Uncertainty in V_r $\epsilon_r = s$				
50 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____		____V				
Freq.	Measurement p-p Volts V_o	Sine Wave Generator Uncertainty ϵ_g	Uncertainty in V_o $\epsilon = \epsilon_g + s$	Flatness $V_o - V_r$	Uncertainty in $V_o - V_r$ $\epsilon + \epsilon_r$	Specification Limits (P-P) Min.	Max.
1 MHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	3.00 mV	____mV	____mV	±____mV	-16.8 mV	16.8 mV
10 MHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	3.00 mV	____mV	____mV	±____mV	-16.8 mV	16.8 mV
100 MHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	3.00 mV	____mV	____mV	±____mV	-16.8 mV	16.8 mV

Table 10.3.2ee-2 Bandwidth - Channel 2 - without Probe 100 mV Range - Sine-Wave Generator Output: 600 mV p-p

Freq.	Measurement p-p Volts V_r		Uncertainty in V_r $\epsilon_r = s$				
50 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____		____V				
Freq.	Measurement p-p Volts V_o	Sine Wave Generator Uncertainty ϵ_g	Uncertainty in V_o $\epsilon = \epsilon_g + s$	Flatness $V_o - V_r$	Uncertainty in $V_o - V_r$ $\epsilon + \epsilon_r$	Specification Limits (P-P) Min.	Max.
1 MHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	6.0 mV	____mV	____mV	±____mV	-33.6 mV	33.6 mV
10 MHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	6.0 mV	____mV	____mV	±____mV	-33.6 mV	33.6 mV
100 MHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	6.0 mV	____mV	____mV	±____mV	-33.6 mV	33.6 mV

Table 10.3.2ff-2 Bandwidth - Channel 2 - without Probe 200 mV Range - Sine-Wave Generator Output: 1.2 V p-p

Freq.	Measurement p-p Volts V_r		Uncertainty in V_r $\epsilon_r = s$				
50 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____		____V				
Freq.	**Measurement p-p Volts V_o**	**Sine Wave Generator Uncertainty ϵ_g**	**Uncertainty in V_o $\epsilon = \epsilon_g + s$**	**Flatness $V_o - V_r$**	**Uncertainty in $V_o - V_r$ $\epsilon + \epsilon_r$**	**Specification Limits (P-P) Min.**	**Max.**
1 MHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.012 V	____mV	____mV	±____mV	-0.067 V	0.067 V
10 MHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.012 V	____mV	____mV	±____mV	-0.067 V	0.067 V
100 MHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.012 V	____mV	____mV	±____mV	-0.352 V	0.067 V

Table 10.3.2gg-2 Bandwidth - Channel 2 - without Probe 500 mV Range - Sine-Wave Generator Output: 3 V p-p

Freq.	Measurement p-p Volts V_r		Uncertainty in V_r $\epsilon_r = s$				
50 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____		____V				
Freq.	Measurement p-p Volts V_o	Sine Wave Generator Uncertainty ϵ_g	Uncertainty in V_o $\epsilon = \epsilon_g + s$	Flatness $V_o - V_r$	Uncertainty in $V_o - V_r$ $\epsilon + \epsilon_r$	Specification Limits (P-P) Min.	Max.
1 MHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.030 V	____mV	____mV	±____mV	-0.168 V	0.168 V
10 MHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.030 V	____mV	____mV	±____mV	-0.168 V	0.168 V
100 MHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.030 V	____mV	____mV	±____mV	-0.879 V	0.168 V

Table 10.3.2hh-2 Bandwidth - Channel 2 - without Probe 1 V Range - Sine-Wave Generator Output: 5.5 V p-p

Freq.	Measurement p-p Volts V_r		Uncertainty in V_r $\epsilon_r = s$
50 kHz	1)______ 2)______ 3)______ 4)______ 5)______ Av______		______V

Freq.	Measurement p-p Volts V_o	Sine Wave Generator Uncertainty ϵ_g	Uncertainty in V_o $\epsilon = \epsilon_g + s$	Flatness $V_o - V_r$	Uncertainty in $V_o - V_r$ $\epsilon + \epsilon_r$	Specification Limits (P-P) Min.	Max.
1 MHz	1)______ 2)______ 3)______ 4)______ 5)______ Av______	0.055 V	______mV	______mV	±______mV	-0.31 V	0.31 V
10 MHz	1)______ 2)______ 3)______ 4)______ 5)______ Av______	0.055 V	______mV	______mV	±______mV	-0.31 V	0.31 V
100 MHz	1)______ 2)______ 3)______ 4)______ 5)______ Av______	0.055 V	______mV	______mV	±______mV	-1.61 V	0.31 V

Table 10.3.2ii-2 Bandwidth - Channel 2 - with Probe 5 V Range - Sine-Wave Generator Output: 30 V p-p

Freq.	Measurement p-p Volts V_o	Flatness at 500 kHz (ΔV)	$V_r = V_o - \Delta V$	Uncertainty in ΔV (ϵ_Δ)	Uncertainty in V_o (s)	Uncertainty in V_r = $\epsilon_r = \epsilon_\Delta + s$
500 kHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	______				

Freq.	Measurement p-p Volts V_o	Sine Wave Generator Uncertainty ϵ_g	Uncertainty in V_o $\epsilon = \epsilon_g + s$	Flatness V_o-V_r	Uncertainty in V_o-V_r $\epsilon + \epsilon_r$	Specification Limits (P-P) Min.	Max.
1 MHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.60 V	____V	____V	±____V	-1.68 V	1.68 V
10 MHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.60 V	____V	____V	±____V	-1.68 V	1.68 V
100 MHz	1)____ 2)____ 3)____ 4)____ 5)____ Av____	0.60 V	____V	____V	±____V	-8.79 V	1.68 V

Table 10.3.2jj-2 Bandwidth - Channel 2 - with Probe 10 V Range - Sine-Wave Generator Output: 60 V p-p

Freq.	Measurement p-p Volts V_o	Flatness at 500 kHz (ΔV)	$V_r = V_o - \Delta V$	Uncertainty in ΔV (ϵ_Δ)	Uncertainty in V_o (s)	Uncertainty in V_r = $\epsilon_r = \epsilon_\Delta + s$
500 kHz	1)______ 2)______ 3)______ 4)______ 5)______ Av______	______				

Freq.	Measurement p-p Volts V_o	Sine Wave Generator Uncertainty ϵ_g	Uncertainty in V_o $\epsilon = \epsilon_g + s$	Flatness $V_o - V_r$	Uncertainty in $V_o - V_r$ $\epsilon + \epsilon_r$	Specification Limits (P-P) Min.	Max.
1 MHz	1)______ 2)______ 3)______ 4)______ 5)______ Av______	1.20 V	______V	______V	±______V	-3.36 V	3.36 V
10 MHz	1)______ 2)______ 3)______ 4)______ 5)______ Av______	1.20 V	______V	______V	±______V	-3.36 V	3.36 V
100 MHz	1)______ 2)______ 3)______ 4)______ 5)______ Av______	1.20 V	______V	______V	±______V	-17.6 V	3.36 V

10.3 Vertical Section

10.3.2.1 DC Coupled Bandwidth

Specification:

The response shall be no more than 3 dB down at 100 MHz and shall be within ± 0.25 dB from DC to 50 KHz.

Equipment:

Items	Model
None	

Note: This procedure utilizes results obtained from the equipment and procedures given in Paragraph 10.3.2. No new measurements are required. This procedure compares the vertical channel frequency response at dc, 10 Hz, 100 Hz, 1 kHz and 10 kHz with the response at 50 kHz (reference frequency). These comparisons are made for both Channel 1 and Channel 2 for all vertical amplifier ranges from 5 mV to 5 V. The 100 MHz response for these ranges is also obtained from the procedures given in Paragraph 10.3.2.

Procedure:

1. Refer to table 10.3.2b-1, the 5 mV range for Channel 1. For all frequencies except 200 kHz, compare the flatness quantity, V_o-V_r, given in column 5 with the Specification limit listed below the double line.

2. Repeat the preceding procedure for the following tables: tables 10.3.2c-1 through 10.3.2.k-1. For each comparison of V_o-V_r with the specification limits, be sure to use the Specification limits listed below the double line. Enter the results of the comparisons in the first row of table 10.3.2.1a.

3. The procedures covered by the above two paragraphs yield the dc - 50 kHz flatness characteristics for Channel 1. To obtain the flatness characteristics for Channel 2, perform the same steps for tables 10.3.2b-2 through 10.3.2k-2. Enter the results of the comparisons in the second row of table 10.3.2.1a.

4. To obtain the 100 MHz response for Channel 1: Refer to table 10.3.2aa-1 for the 100 MHz frequency response in the 5 mV/div range. Compare the flatness quantity, V_o-V_r shown in column 6 with the specification limits.

5. The 100 MHz response for successively larger vertical amplifier ranges are obtained by making similar comparisons of V_o-V_r with the specification limits in tables 10.3.2cc-1 through 10.3.2jj-1.

6. The procedures covered by the two preceding paragraphs yield the 100 MHz responses for Channel 1. To obtain the 100 MHz flatness characteristic for Channel 2, perform the same steps for tables 10.3.2aa-2 through 10.3.2jj-2.

7. Enter the results of the comparisons made in steps 5 and 6 in table 10.3.2.1b.

Table 10.3.2.1a DC Coupled Bandwidth for dc - 50 kHz Range

Tables Examined	Were Values of (V_o-Vr) within Specified Limits?	
	Yes	No
10.3.2b-1 through 10.3.2k-1		
10.3.2b-2 through 10.3.2k-2		

Table 10.3.2.1b DC Coupled Bandwidth Check at 100 MHz.

Tables Examined	Were Values of (V_o-Vr) within Specified Limits?	
	Yes	No
10.3.2aa-1 through 10.3.2hh-1		
10.3.2aa-2 through 10.3.2hh-2		

10.3.2.2 AC Coupled Bandwidth

Specification:

The response shall be no more than 3 dB down at 10 Hz and at 100 MHz.

Equipment:

Items	Model
AC Meter Calibrator	Fluke Model 5200A or equivalent
BNC male to BNC male coaxial 3 feet long	Tektronix P/N012-0482-00 or equivalent
BNC female to banana plug adapter	Pomona 1269
Sine-Wave Generator	Tektronix Model SG 503 or equivalent

Part 1: 10 Hz bandwidth

1. Connect the ac calibrator output to Channel 2 of the storage oscilloscope as shown below.

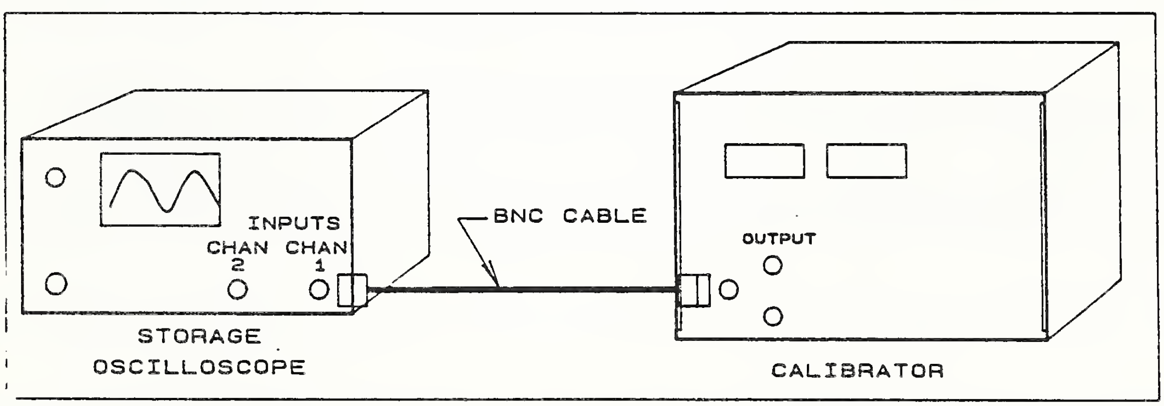


Figure 10.3.2.2a Test setup for measuring the oscilloscope response at 10 Hz for ac coupling

2. Set the rms voltage of the ac calibrator to 106.1 mV and the frequency to 10 Hz.

3. Set the input coupling to the two channels of the storage oscilloscope to dc and to 50 Ω OFF (i.e., high input impedance). Set the range of the vertical amplifiers of both channels to 50 mV/div and select Channel 1.

4. Use the cursors in the delta voltage mode to measure the peak-to-peak voltage. Record the CRT readout of this value in column 2, row 1 of table 10.3.2.2a.

5. Set the input coupling to ac and again use the cursors to measure the peak-to-peak voltage. Record the CRT readout of this value in column 3, row 1 of the table.

6. Compute Eac/Edc, and enter the result in column 4.

7. Select Channel 2 of the oscilloscope and connect the calibrator output to Channel 2.

8. Use the cursors to measure the peak-to-peak voltage. Record the CRT readout and record this value in column 2, row 2 of table 10.3.2.2a.

9. Set the input coupling to ac and measure the peak-to-peak voltage. Record this value in column 3, row 2 of the table.

10. Compute Eac/Edc and enter the result in column 4.

Table 10.3.2.2a. AC Coupled Bandwidth - Response Measurement at 10 Hz

Input Channel	P-P Voltage DC Coupling (Edc)	P-P Voltage AC Coupling (Eac)	Eac/Edc	Estimated Uncertainty	Specification Limit	
					Min	Max
1	________	________	________	±0.02	0.707	None
2	________	________	________	±0.02	0.707	None

Part 2: 100 MHz bandwidth

11. Connect the sine-wave generator output to Channel 1, using the specified cable and a 50 Ω termination connected directly to the Channel 1 input as shown in figure 10.3.2.2b.

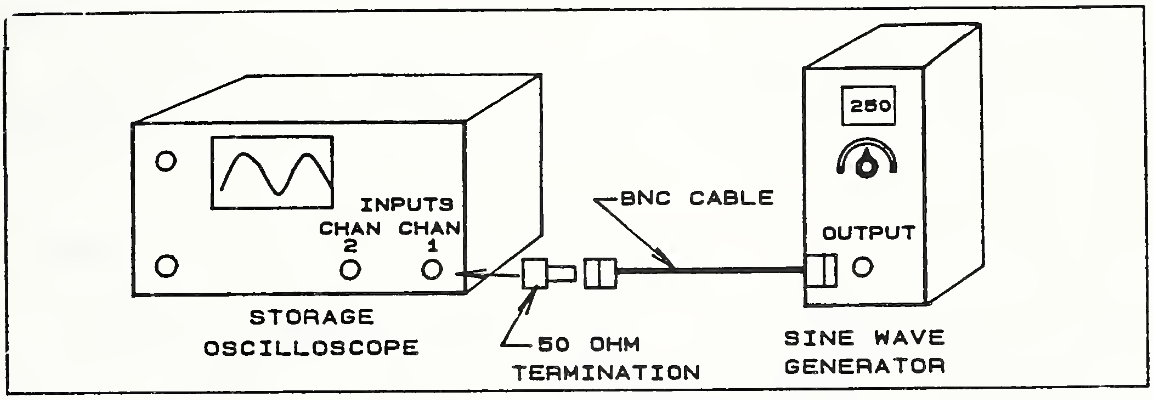


Figure 10.3.2.2b Test setup for measuring the oscilloscope response at 100 MHz for ac coupling

12. Set the input coupling to the two channels of the storage oscilloscope to ac and to 50 Ω OFF. Set the range of the vertical amplifiers of both channels to 50 mV/cm. Select Channel 1 of the oscilloscope and

13. Set the frequency of the sine-wave generator to 50 kHz and adjust the output amplitude for a displayed amplitude of 300 mV p-p.

14. Use the cursors in the delta voltage mode to make 5 independent measurements of the peak-to-peak amplitude. Record these values in the first data row of table 10.3.2.2b. Calculate the average (Av) and standard deviation, s, of these values. Record these quantities. Note that the average, A_v, is the reference voltage, V_r, and the uncertainty of V_r is $\epsilon_r = s$.

15. Without changing the sine-wave generator output amplitude setting, change the frequency to 100 MHz.

16. Use the cursors in the delta mode to make 5 independent measurements of the peak-to-peak amplitude. Record these values in the second data row of the table. Calculate the values of A_v. and s. Record A_v and e_g + s. Note that A_v is the voltage V_o. Using V_r and ϵ_r from the preceding data row, calculate V_o-V_r and $\epsilon + \epsilon_r$. Check to see that the value of V_o-V_r is within the specification limits.

17. Select Channel 2 of the storage oscilloscope and connect the sine-wave generator output to Channel 2, using the same cable and termination, as before.

18. Repeat steps 13 through 16 for Channel 2, recording the data and performing the operations listed in data rows 3 and 4 of table 10.3.2b.

Table 10.3.2.2b AC Coupled Bandwidth - Response at 100 MHz

Channel 1							
Freq.	Measurement p-p Volts, V_r	Uncertainty in Vr $\epsilon_r = s$					
50 kHz	1)______ 2)______ 3)______ 4)______ 5)______ Av______	______					
Freq.	Measurement p-p Volts V_o	Generator Uncertainty ϵ_g	Uncertainty in V_o $\epsilon=(\epsilon_g+s)$	Flatness $V_o - V_r$	Uncertainty in $V_o - V_r$ $(\epsilon+\epsilon_r)$	Specification Limits (mV) Min.	Max.
100 MHz	1)______ 2)______ 3)______ 4)______ 5)______ Av______	3mV p-p	______	______	±______	-87.9 mV	16.8 mV

Channel 2							
Freq.	Measurement p-p Volts, V_r	Uncertainty in $\epsilon_r = s$					
50 kHz	1)______ 2)______ 3)______ 4)______ 5)______ Av______	______					
Freq.	Measurement p-p Volts V_o	Generator Uncertainty ϵ_g	Uncertainty in V_o $\epsilon=(\epsilon_g+s)$	Flatness V_o-Vr	Uncertainty in V_o-Vr $(\epsilon+\epsilon_r)$	Specification Limits (mV) Min.	Max.
100 MHz	1)______ 2)______ 3)______ 4)______ 5)______ Av______	3mV p-p	______	______	±______	-87.9 mV	16.8 mV

10.3 Vertical Section

10.3.3 Transient Response (Overshoot and Undershoot)

<u>Specification:</u>

The transient response aberrations of each vertical channel shall be within 4 percent p-p for a 6 division step input pulse with a rise time not greater than 0.3 nsec.

<u>Equipment</u>:

<u>Items</u>	<u>Model</u>
Step Generator	Picosecond Pulse Labs Model 2700 pulse generator or equivalent
Male SMA to female BNC adapter	American 2082-2320 or equivalent
One 12" Coaxial Cable with Male BNC connectors	Pomona 4531-24
Female BNC to male N adapter	Pasternack PE9074 or equivalent

<u>Procedure</u>:

1. Set both channels of the storage oscilloscope for a range of 20 mV/div and a sweep speed of 5ns/div. Set the coupling of the channels to dc 50Ω ON. Set the triggering to INTERNAL.

2. Set the attenuator of the pulse generator to approximately 55 dB, and connect it to Channel 1 of the oscilloscope as shown in figure 10.3.3a.

3. Adjust the generator attenuator and the scope offset for a voltage step size of 6 major divisions (a transition from - 3 div. to + 3 div.).

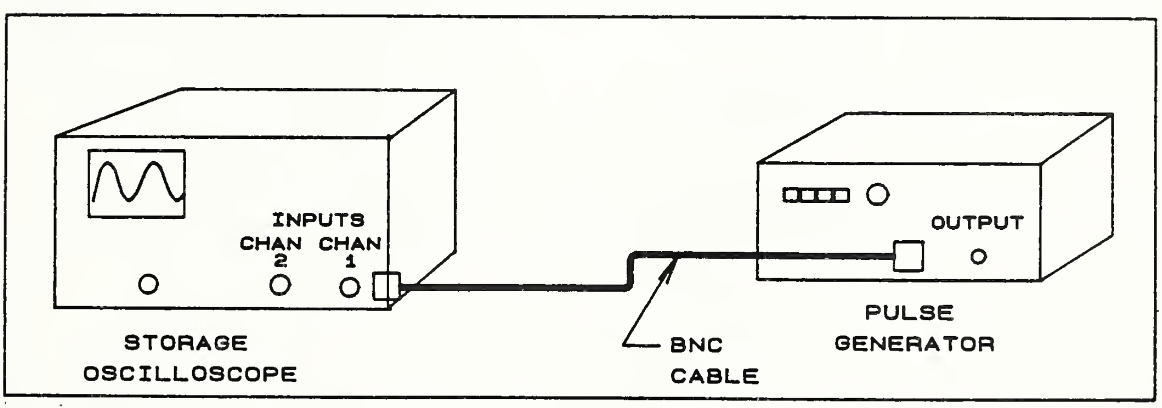


Figure 10.3.3a Test setup for measuring transient response (overshoot and undershoot)

4. Use the cursors in the delta voltage mode to measure the p-p distortion of the waveform following the step transition, and prior to its settling to a smooth top line. See figure 10.3.3b for an illustration.

5. Enter the p-p readout into table 10.3.3. Check to see that the specification limit is not exceeded.

6. Now select Channel 2 and connect the generator output to this channel. Repeat steps 3, 4, and 5.

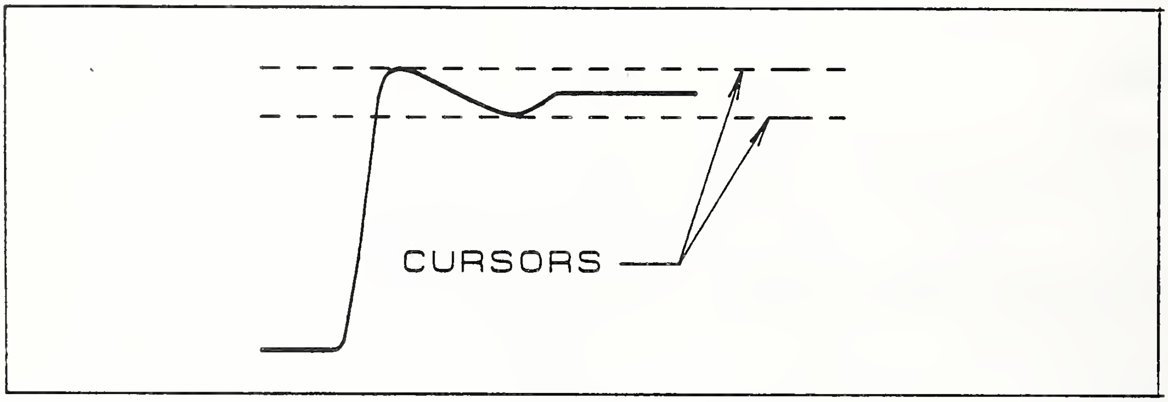


Figure 10.3.3b Display of the measurement of P-P distortion of voltage step, using cursors

Table 10.3.3 Transient Response (Overshoot and Undershoot) Measurements

Channel No.	Measured P-P Distortion (mV)	Estimated Measurement Uncertainty	Specification Limit (P-P)
1	________	±2 mV	4.8 mV
2	________	±2 mV	4.8 mV

10.3 Vertical Section

10.3.4 Deflection Factors

Specification:

The minimum range for calibrated vertical channel deflection factors of each channel shall be from 5 millivolts per division or less to 5 volts per division or more for both AC and DC coupling. Ranging shall be in a 5-2-1 sequence.

Equipment:

Items	Model
None	

Procedure:

1. Examine the storage oscilloscope to assure that the Channel 1, dc deflection factors are provided in accordance with the values given in table 10.3.4a

2. Record the compliance (or lack of compliance) of this specification in table 10.3.4a

3. Repeat steps 1 and 2 to assure that the Channel 2, dc deflection factors are provided in accordance with the values given in table 10.3.4b.

4. Repeat steps 1 and 2 to assure that the Channel 1, ac deflection factors are provided in accordance with the values given in table 10.3.4c.

5. Repeat steps 1 and 2 to assure that the Channel 2, ac deflection factors are provided in accordance with the values given in table 10.3.4d.

Table 10.3.4a Deflection Factors - Channel 1 - DC

Measurement Description	Measurement Data	Estimated Measurement Uncertainty	Specification Limits Min.	Max.	Units
5 V/division factor exists?	____________	N/A	Yes		
2 V/division factor exists?	____________	N/A	Yes		
1 V/division factor exists?	____________	N/A	Yes		
500 mV/div'n factor exists?	____________	N/A	Yes		
200 mV/div'n factor exists?	____________	N/A	Yes		
100 mV/sweep factor exists?	____________	N/A	Yes		
50 mV/div'n factor exists?	____________	N/A	Yes		
20 mV/div'n factor exists?	____________	N/A	Yes		
10 mV/div'n factor exists?	____________	N/A	Yes		
5 mv/div'n factor exists?	____________	N/A	Yes		

Table 10.3.4b Deflection Factors - Channel 2 - DC

Measurement Description	Measurement Data	Estimated Measurement Uncertainty	Specification Limits Min.	Max.	Units
5 V/division factor exists?	____________	N/A	Yes		
2 V/division factor exists?	____________	N/A	Yes		
1 V/division factor exists?	____________	N/A	Yes		
500 mV/div'n factor exists?	____________	N/A	Yes		
200 mV/div'n factor exists?	____________	N/A	Yes		
100 mV/sweep factor exists?	____________	N/A	Yes		
50 mV/div'n factor exists?	____________	N/A	Yes		
20 mV/div'n factor exists?	____________	N/A	Yes		
10 mV/div'n factor exists?	____________	N/A	Yes		
5 mv/div'n factor exists?	____________	N/A	Yes		

Table 10.3.4c Deflection Factors - Channel 1 - AC

Measurement Description	Measurement Data	Estimated Measurement Uncertainty	Specification Limits Min.	Specification Limits Max.	Units
5 V/division factor exists?	______________	N/A	Yes		
2 V/division factor exists?	______________	N/A	Yes		
1 V/division factor exists?	______________	N/A	Yes		
500 mV/div'n factor exists?	______________	N/A	Yes		
200 mV/div'n factor exists?	______________	N/A	Yes		
100 mV/sweep factor exists?	______________	N/A	Yes		
50 mV/div'n factor exists?	______________	N/A	Yes		
20 mV/div'n factor exists?	______________	N/A	Yes		
10 mV/div'n factor exists?	______________	N/A	Yes		
5 mv/div'n factor exists?	______________	N/A	Yes		

Table 10.3.4d Deflection Factors - Channel 2 - AC

Measurement Description	Measurement Data	Estimated Measurement Uncertainty	Specification Limits Min.	Max.	Units
5 V/division factor exists?	________	N/A	Yes		
2 V/division factor exists?	________	N/A	Yes		
1 V/division factor exists?	________	N/A	Yes		
500 mV/div'n factor exists?	________	N/A	Yes		
200 mV/div'n factor exists?	________	N/A	Yes		
100 mV/sweep factor exists?	________	N/A	Yes		
50 mV/div'n factor exists?	________	N/A	Yes		
20 mV/div'n factor exists?	________	N/A	Yes		
10 mV/div'n factor exists?	________	N/A	Yes		
5 mv/div'n factor exists?	________	N/A	Yes		

10.3 Vertical Section

10.3.4.1 Uncalibrated Vertical Vernier

Specification:

The deflection factor shall be continuously variable between all ranges and extend the maximum deflection factor to at least 12 volts per division. This is not required for digital oscilloscopes.

Equipment:

Items	Model
DC Meter Calibrator	Fluke 5101B or equivalent
BNC female to Banana Plug Adapter	Pomona 1269 or equivalent
BNC Male to BNC Male Coaxial Cable 24 inches (61 cm) ea.	Pomona BNC-C-24 or equivalent

Procedure:

Part 1: Minimum deflection factor of 12 volts per division

1. Determine if the storage oscilloscope is a digital oscilloscope as defined in the NOTES, Item 9, p.3. If the oscilloscope is a digital oscilloscope, do not perform this test.

2. Set the controls of the storage oscilloscope to the default values given in NOTES, Item 4, p.1. Change the following controls from the default values to that shown below.

   Vertical Controls (both channels)
   VOLTS/DIV 5 V

3. Connect the equipment as shown below.

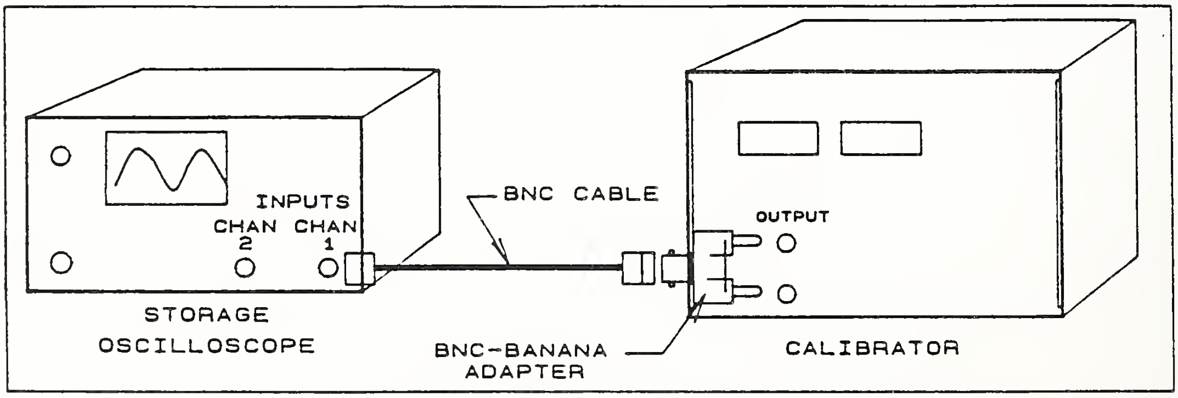


Figure 10.3.4.1 Test setup for demonstration of uncalibrated vertical vernier

4. Assure that the trace is centered on the horizontal centerline of the screen.

5. Apply 36 volts dc from the meter calibrator to the vertical CHANNEL 1 input. The trace should be deflected off the top of the screen. (The voltage of 36 volts should produce 3 divisions of deflection at 12 V/div.)

6. Adjust the vertical vernier control of the storage oscilloscope such that the trace is brought back onto the screen. Continue to adjust the vertical vernier control to produce the minimum deflection of the trace.

7. Read and record in tables 10.3.4.1a the vertical deflection of the trace.

Part 2: The deflection factor is continuously variable.

8. Change the following controls to that shown below.

Vertical Controls (both channels)	
VOLTS/DIV	5 mV

9. Apply a voltage from the meter calibrator to the vertical CHANNEL 1 input of the storage oscilloscope equal to three times the volts/div range set on the oscilloscope. (For the 5 mV/div range, for example, the value set on the meter calibrator would be 15 mV.)

10. Adjust the vertical vernier control such that the deflection of the trace is maximum. Read and record in tables 10.3.4.1a through 10.3.4.1c, for the particular range, the voltage corresponding to the maximum deflection, as displayed on the storage oscilloscope, as Vmax. (The value of Vmax is found by dividing the deflection, in major divisions, by the range in volts/division.)

11. Adjust the vertical vernier control such that the deflection of the trace is minimum. Read and record on the data sheet, for the particular range, the voltage corresponding to the minimum deflection, as displayed on the storage oscilloscope, as Vmin. (The value of Vmin is found by dividing the deflection, in major divisions, by the range in volts/division.)

12. Switch the vertical range control to the next higher range and repeat steps 10 and 11.

13. Record in tables 10.3.4.1a through 10.3.4.1c that the deflection factor is continuously variable between all ranges by assuring that the minimum deflection of a lower range exceeds the maximum deflection of the next higher range. Record the compliance (or lack of compliance) of this specification in the tables.

Table 10.3.4.1a Uncalibrated Vertical Vernier

Measurement Description	Measurement Data	Estimated Measurement Uncertainty	Specification Limits Min.	Max.	Units
Maximum defl. factor	____________	0.0058	12		V/div
5 mV/div range, Vmin	____________				
5 mv/div range, Vmax	____________				
10 mV/div range, Vmin	____________				
10 mV/div range, Vmax	____________				
Are ranges continuous?	____________	N/A	Yes		
20 mV/div range, Vmin	____________				
20 mV/div range, Vmax	____________				
Are ranges continuous?	____________	N/A	Yes		
50 mV/div range, Vmin	____________				
50 mV/div range, Vmax	____________				
Are ranges continuous?	____________	N/A	Yes		

Table 10.3.4.1b Uncalibrated Vertical Vernier - con't

Measurement Description	Measurement Data	Estimated Measurement Uncertainty	Specification Limits Min.	Max.	Units
100 mV/div range, Vmin	________				
100 mV/div range, Vmax	________				
Are ranges continuous?	________	N/A	Yes		
200 mV/div range, Vmin	________				
200 mV/div range, Vmax	________				
Are ranges continuous?	________	N/A	Yes		
0.5 V/div range, Vmin	________				
0.5 V/div range, Vmax	________				
Are ranges continuous?	________	N/A	Yes		
1 V/div range, Vmin	________				
1 V/div range, Vmax	________				
Are ranges continuous?	________	N/A	Yes		

Table 10.3.4.1c Uncalibrated Vertical Vernier - con't

Measurement Description	Measurement Data	Estimated Measurement Uncertainty	Specification Limits Min.	Max.	Units
2 V/div range, Vmin	________				
2 V/div range, Vmax	________				
Are ranges continuous?	________	N/A	Yes		
5 V/div range, Vmin	________				
5 V/div range, Vmax	________				
Are ranges continuous?	________	N/A	Yes		

10.3.4.2 Vertical Deflection Factor Accuracy

Specification:

The vertical deflection factor accuracy of each vertical channel and each vertical deflection factor range setting shall be within:

a. *±2 percent of full scale at any temperature between 0 degrees C and 40 degrees C without probe.*

b. *±3 percent of full scale at any temperature between 40 degrees C and 55 degrees C without probe.*

Note: This procedure utilizes results obtained from the procedure given in Paragraph 10.3.2. No new measurements are required.

Equipment:

Items	Model
None	

Procedure:

1. Transfer the values of V_r (average value, A_v) given in column 3 of table 10.3.2a-1 to the corresponding locations (i.e. same range) of column 4 in table 10.3.4.2-1.

2. Transfer the values of ϵ_r given in the right-hand column of table 10.3.2a-1 to the corresponding locations of column 5 in table 10.3.4.2-1.

3. Transfer the values of V_r given in column 3 of table 10.3.2a-2 to the corresponding locations of column 4 in table 10.3.4.2-2.

4. Transfer the values of ϵ_r given in the right-hand column of table 10.3.2a-2 to the corresponding locations of column 5 in table 10.3.4.2-2.

5. For both tables (10.3.4.2-1 and 10.3.4.2-2), compare the values of V_r with the corresponding Specification Limits.

Table 10.3.4.2-1 Vertical Deflection Factor Accuracy - Channel 1 - without Probe. Calibrator Frequency: 50 kHz. Measured P-P Voltages and Uncertainties in V_r Taken from Table 10.3.2.a-1

Voltage Range	Calibrator Output (rms)	Calibrator Output (P-P)	Measured P-P Voltage (V_r)	Uncertainty in V_r (ϵ_r)	Specification Limits P-P Min	Max
5mV	106.1 mV Use 10:1 Attenuator	30 mV (Attenuator Output)	______	±______	29.4 mV	30.6 mV
10mV	212.2 mV Use 10:1 Attenuator	60 mV (Attenuator Output)	______	±______	58.8 mV	61.2 mV
20mV	424 mV Use 10:1 Attenuator	120 mV (Attenuator Output)	______	±______	117.6 mV	112.4 mV
50mV	106.1 mV	300 mV	______	±______	294. mV	306. mV
100mV	212.2 mV	600 mV	______	±______	588 mV	612 mV
200mV	424 mV	1.2 V	______	±______	1.176V	1.224V
500mV	1.061 V	3.0 V	______	±______	2.94V	3.06V
1 V	2.122 V	6.0 V	______	±______	5.88V	6.12V
2 V	4.24 V	12.0 V	______	±______	11.76V	12:24V
5 V	10.61 V	30 V	______	±______	29.4V	30.6V

Table 10.3.4.2-2 Vertical Deflection Factor Accuracy - Channel 2 - without Probe. Calibrator Frequency: 50 kHz. Measured P-P Voltages and Uncertainties in V_r Taken from Table 10.3.2.a-2

Voltage Range	Calibrator Output (rms)	Calibrator Output (P-P)	Measured P-P Voltage (V_r)	Uncertainty in V_r (ϵ_r)	Specification Limits P-P Min	Max
5mV	106.1 mV Use 10:1 Attenuator	30 mV (Attenuator Output)	______	±______	29.4 mV	30.6 mV
10mV	212.2 mV Use 10:1 Attenuator	60 mV (Attenuator Output)	______	±______	58.8 mV	61.2 mV
20mV	424 mV Use 10:1 Attenuator	120 mV (Attenuator Output)	______	±______	117.6 mV	112.4 mV
50mV	106.1 mV	300 mV	______	±______	294. mV	306. mV
100mV	212.2 mV	600 mV	______	±______	588 mV	612 mV
200mV	424 mV	1.2 V	______	±______	1.176V	1.224V
500mV	1.061 V	3.0 V	______	±______	2.94V	3.06V
1 V	2.122 V	6.0 V	______	±______	5.88V	6.12V
2 V	4.24 V	12.0 V	______	±______	11.76V	12.24V
5 V	10.61 V	30 V	______	±______	29.4V	30.6V

10.3 Vertical Section

10.3.4.3 Overload Protection

Specification:

The equipment shall be capable of withstanding, for a minimum time of 5 minutes, at any vertical range setting without damage and the vertical channels AC or DC coupled up to:

a. 400V (DC + Peak AC), 800V P-P AC at 10K Hz or less, for 1 M ohms input impedance.

b. 5V rms, for 50 ohms input impedance.

Equipment:

Items	Model
DC Meter Calibrator	Fluke 5101B or equivalent
AC Meter Calibrator	Fluke 5200A or equivalent
Precision Power Amplifier	Fluke 5205A or equivalent
Function Generator	HP 3325 Synthesizer/Function Generator or equivalent
Clock	General Electric 2908 or equivalent
BNC female to Banana Plug Adapter	Pomona 1269 or equivalent
BNC Male to BNC Male Coaxial Cable 24 inches (61 cm) ea.	Pomona BNC-C-24 or equivalent

Procedure:

WARNING: This procedure uses lethal voltages during the test. Care should be taken to avoid injury or shock.

1. Set the controls of the storage oscilloscope to the default values given in NOTES, Item 4, p.1. Change the following controls from the default values to that shown below.

   Vertical Controls (both channels)

VOLTS/DIV	5 mV
COUPLING	DC

2. Connect the equipment as shown below.

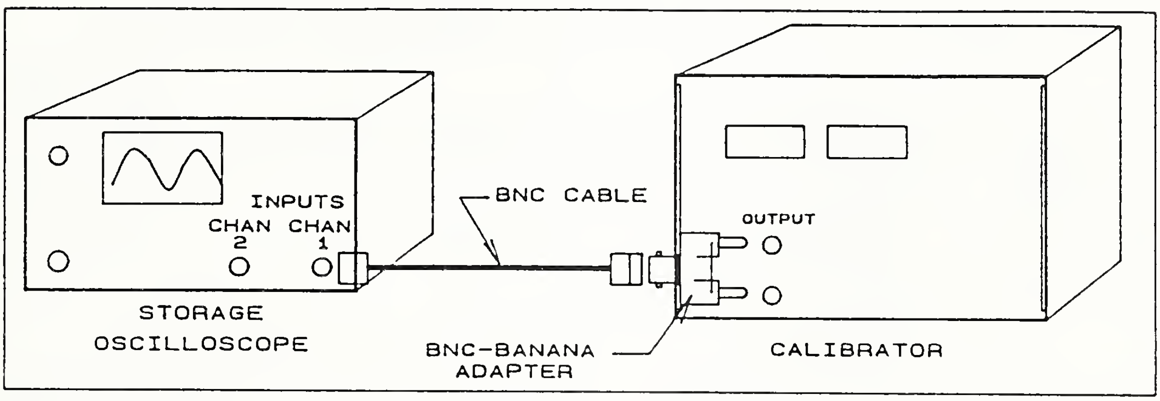


Figure 10.3.4.3a Test setup for measurement of dc overload protection - 1 MΩ

3. Apply 400 volts dc from the meter calibrator to the vertical CHANNEL 1 input. Note time on the clock.

4. After 5 minutes has elapsed, note any evidence of smoking, arcing, or charring of the storage oscilloscope. Note the presence of any evidence of damage in table 10.3.4.3a.

5. Remove the voltage from the calibrator to the storage oscilloscope.

6. Apply -400 volts dc from the meter calibrator to the vertical CHANNEL 1 input. Note time on the clock.

7. After 5 minutes has elapsed, note any evidence of smoking, arcing, or charring of the storage oscilloscope. Note the presence of any evidence of damage in table 10.3.4.3a.

8. Connect the equipment as shown below.

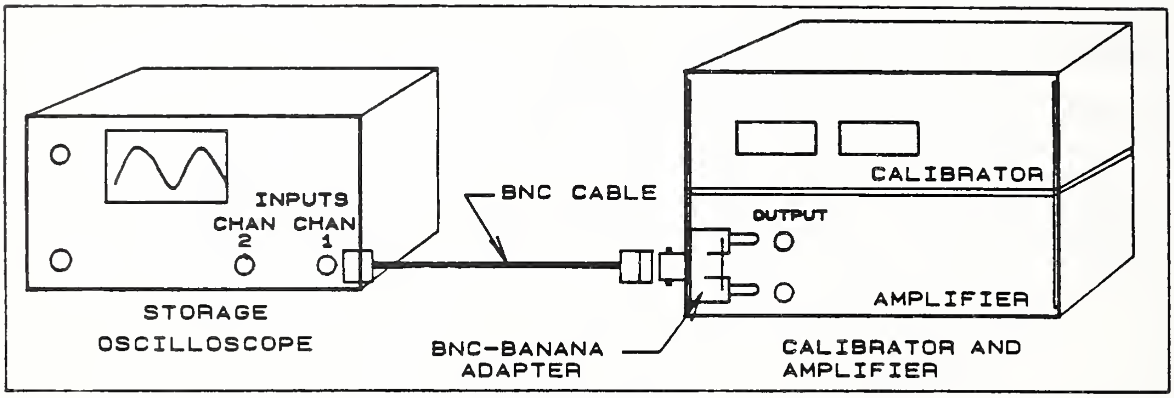


Figure 10.3.4.3b Test setup for measurement of overload protection - 1 MΩ

9. Remove the voltage from the storage oscilloscope, and apply a 282.885 vac rms (800 V peak-to-peak), 10 kHz signal to the vertical CHANNEL 1 input.

10. After 5 minutes has elapsed, note any evidence of smoking, arcing, or charring of the storage oscilloscope. Note the presence of any evidence of damage in table 10.3.4.3a.

11. Repeat steps 9 and 10 for the vertical CHANNEL 2 input.

12. Connect the equipment as shown below.

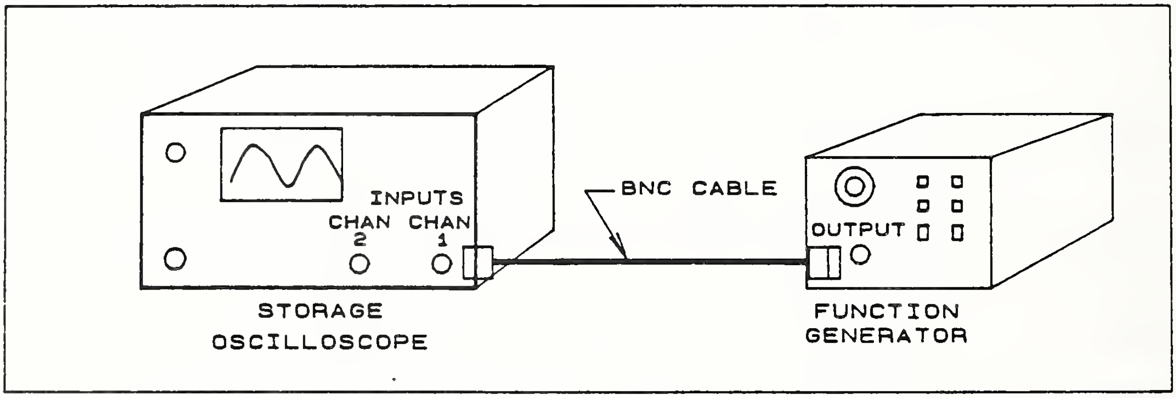


Figure 10.3.4.3c Test setup for measurement of overload protection - 50 Ω

13. Set the controls of the storage oscilloscope to the default values given in NOTES, Item 4, p.1. to that given below.

Vertical Controls (both channels)

VOLTS/DIV	5 mV
IMPEDANCE	50 Ω

14. Apply 5.0 V ac rms (10 V peak-to-peak) square wave signal at a frequency of 10 kHz signal to the vertical CHANNEL 1 input.

15. After 5 minutes has elapsed, note any evidence of smoking, arcing, or charring of the storage oscilloscope. Note the presence of any evidence of damage in table 10.3.4.3a.

16. Repeat steps 14 and 15 for the vertical CHANNEL 2 input.

17. Change the following controls from the default values to that shown below.

    Vertical Controls (both channels)
    COUPLING AC

18. Repeat steps 2 through 16 and record the data in table 10.3.4.3b.

Table 10.3.4.3a Overload Protection - DC Coupled

Measurement Description	Measurement Data	Estimated Measurement Uncertainty	Specification Limits Min.	Max.	Units
Channel 1-1 MΩ DC overload	________	N/A	No damage		
Channel 1-1 MΩ -DC overload	________	N/A	No damage		
Channel 2-1 MΩ DC overload	________	N/A	No damage		
Channel 2-1 MΩ -DC overload	________	N/A	No damage		
Channel 1-1 MΩ AC overload	________	N/A	No damage		
Channel 2-1MΩ AC overload	________	N/A	No damage		
Channel 1-50 Ω AC overload	________	N/A	No damage		
Channel 2-50 Ω AC overload	________	N/A	No damage		

Table 10.3.4.3b Overload Protection - AC Coupled

Measurement Description	Measurement Data	Estimated Measurement Uncertainty	Specification Limits Min.	Max.	Units
Channel 1-1 MΩ DC overload	________	N/A	No damage		
Channel 1-1 MΩ -DC overload	________	N/A	No damage		
Channel 2-1 MΩ DC overload	________	N/A	No damage		
Channel 2-1 MΩ -DC overload	________	N/A	No damage		
Channel 1-1 MΩ AC overload	________	N/A	No damage		
Channel 2-1MΩ AC overload	________	N/A	No damage		
Channel 1-50 Ω AC overload	________	N/A	No damage		
Channel 2-50 Ω AC overload	________	N/A	No damage		

10.3 Vertical Section

10.3.5 Input Impedance

Specification:

The input impedance at all sensitivity settings of each vertical channel shall be 1 megohm ±1.5% shunted by no more than 20 pF. Switchable input impedance to 50 ohms ±1% shall be provided.

Equipment:

Items	Model
LF Impedance Analyzer	HP 4192A or equivalent
Digital Multimeter	Fluke 8506-02A or equivalent
BNC female to Banana Plug Adapter, 2 ea.	Pomona 1269 or equivalent
BNC Male to BNC Male Coaxial Cable 24 inches (61 cm), 2 ea.	Pomona BNC-C-24 or equivalent
Isolation Transformer	Topaz 91002-22 or equivalent
Three-wire-female to two-wire-male adapter	Carol, Type ME or equivalent

Procedure:

Part 1. Input Impedance - 1 MΩ / 20 pF

1. Connect the equipment as shown below.

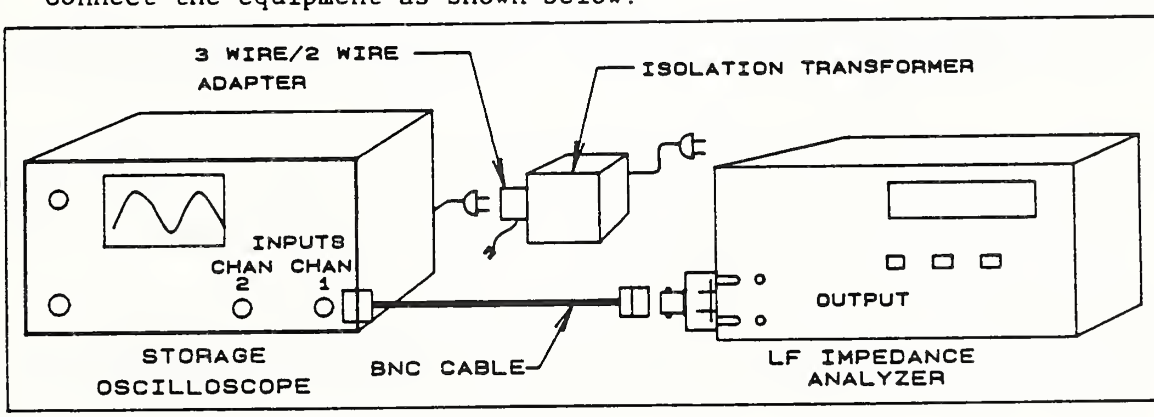


Figure 10.3.5a Test setup for measuring input impedance - 1 MΩ / 20 pF.

Caution:	This procedure requires that the chassis of the storage oscilloscope be ungrounded with respect to earth ground. Assure that adequate safety precautions are observed.

2. Set the controls of the storage oscilloscope to the default values given in NOTES, Item 4, p.1. Change the following controls from the default position to that shown below.

   Vertical Controls (both channels)

VOLTS/DIV	5 mV

3. Set the controls on the analyzer as follows:

DC Bias	OFF
Circuit Mode	PRL
Displays	C and R/G
Test Signal	1 kHz
LCR Range	AUTO
ZY Range	AUTO
Trigger	INT
OSC Level	1.0V*

   *OSC level may be reduced (10mV) for higher sensitivity oscilloscope settings (mV/div), should unstable or inconsistent readings occur

4. Disconnect the cable to the input of the CHANNEL 1 vertical input connector.

5. Read and record the value of the cable capacitance, C_c, as indicated by the analyzer in tables 10.3.5a and 10.3.5b, or use zeroing procedure as specified by manufacturer.

6. Reconnect the cable to the input of the CHANNEL 1 vertical input connector.

7. Read and record the value of the sum of the cable and input capacitance, Cm, of the CHANNEL 1 vertical input as indicated by the analyzer in tables 10.3.5a and 10.3.5b.

8. Subtract the value of the capacitance obtained in step 5 from the value of the capacitance obtained in step 7. Record this difference in tables 10.3.5a and 10.3.5b as, Ci, the input capacitance of the CHANNEL 1 vertical input at 5 mV sensitivity.

9. Read and record the value of the input resistance of the CHANNEL 1 vertical input at 5 mV sensitivity, Ri, as indicated on the analyzer in tables 10.3.5a and 10.3.5b. Use set-up as shown in Figure 10.3.5b.

10. Repeat steps 7 through 10 for each of the vertical defection sensitivities provided on CHANNEL 1.

11. Repeat steps 7 though 11 for CHANNEL 2 vertical input and record the data in tables 10.3.5c and 10.3.5d.

Part 2. Input Impedance - 50 Ω

12. Connect the equipment as shown below.

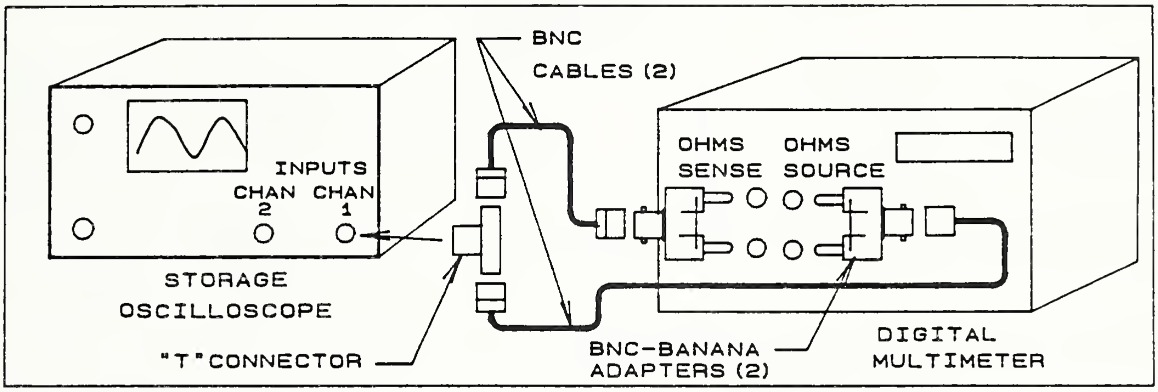


Figure 10.3.5b Test setup for measuring input impedance - 50 Ω.

13. Set the controls of the storage oscilloscope to the default values given in NOTES, Item 4, p.1. Change the following controls from the default position to that shown below.

Vertical Controls (both channels)

VOLTS/DIV	5 mV
COUPLING	DC
IMPEDANCE	50 Ω

14. Assure that the links at the input terminals of the digital multimeter are disconnected between the two sets of terminals marked HI and LO. The link between LO and GRN should be connected, however. Depress the buttons on the digital multimeter in the following order:

RESET
OHMS

15. Read and record the value of the input resistance of the CHANNEL 1 vertical input at 5 mV sensitivity as indicated on the digital multimeter display in table 10.3.5e.

16. Repeat step 15 for each of the vertical defection sensitivities provided on CHANNEL 1.

17. Repeat steps 15 and 16 for CHANNEL 2 vertical input and record the data in table 10.3.5f.

Table 10.3.5a Input Impedance - 1 MΩ / 20 pF - Channel 1

Measurement Description	Measurement Data	Estimated Measurement Uncertainty	Specification Limits Min.	Max.	Units
Cable Capacitance	C_c ______				pF
5 mV Range	Cm ______ Ci ______	±0.15		20.	pF
5 mV Range	Ri ______	±0.003	0.985	1.015	MΩ
10 mV Range	Cm ______ Ci ______	±0.15		20.	pF
10 mV Range	Ri ______	±0.003	0.985	1.015	MΩ
20 mV Range	Cm ______ Ci ______	±0.15		20.	pF
20 mV Range	Ri ______	±0.003	0.985	1.015	MΩ
50 mV Range	Cm ______ Ci ______	±0.15		20.	pF
50 mV Range	Ri ______	±0.003	0.985	1.015	MΩ
100 mV Range	Cm ______ Ci ______	±0.15		20.	pF
100 mV Range	Ri ______	±0.003	0.985	1.015	MΩ

Table 10.3.5b Input Impedance - 1 MΩ / 20 pF - Channel 1 - con't

Measurement Description	Measurement Data	Estimated Measurement Uncertainty	Specification Limits Min.	Max.	Units
200 mV Range	Cm______ Ci______	±0.15		20.	pF
200 mV Range	Ri______	±0.003	0.985	1.015	MΩ
0.5 V Range	Cm______ Ci______	±0.15		20.	pF
0.5 V Range	Ri______	±0.003	0.985	1.015	MΩ
1 V Range	Cm______ Ci______	±0.15		20.	pF
1 V Range	Ri______	±0.003	0.985	1.015	MΩ
2 V Range	Cm______ Ci______	±0.15		20.	pF
2 V Range	Ri______	±0.003	0.985	1.015	MΩ
5 V Range	Cm______ Ci______	±0.15		20.	pF
5 V Range	Ri______	±0.003	0.985	1.015	MΩ

Table 10.3.5c Input Impedance - 1 MΩ / 20 pF - Channel 2

Measurement Description	Measurement Data	Estimated Measurement Uncertainty	Specification Limits Min.	Max.	Units
Cable Capacitance	C_c ______				pF
5 mV Range	Cm______ Ci______	±0.15		20.	pF
5 mV Range	Ri______	±0.003	0.985	1.015	MΩ
10 mV Range	Cm______ Ci______	±0.15		20.	pF
10 mV Range	Ri______	±0.003	0.985	1.015	MΩ
20 mV Range	Cm______ Ci______	±0.15		20.	pF
20 mV Range	Ri______	±0.003	0.985	1.015	MΩ
50 mV Range	Cm______ Ci______	±0.15		20.	pF
50 mV Range	Ri______	±0.003	0.985	1.015	MΩ
100 mV Range	Cm______ Ci______	±0.15		20.	pF
100 mV Range	Ri______	±0.003	0.985	1.015	MΩ

Table 10.3.5d Input Impedance - 1 MΩ / 20 pF - Channel 2 - con't

Measurement Description	Measurement Data	Estimated Measurement Uncertainty	Specification Limits Min.	Max.	Units
200 mV Range	Ri_____	±0.003	0.985	1.015	MΩ
0.5 V Range	Cm_____ Ci_____	±0.15		20.	pF
0.5 V Range	Ri_____	±0.003	0.985	1.015	MΩ
1 V Range	Cm_____ Ci_____	±0.15		20.	pF
1 V Range	Ri_____	±0.003	0.985	1.015	MΩ
2 V Range	Cm_____ Ci_____	±0.15		20.	pF
2 V Range	Ri_____	±0.003	0.985	1.015	MΩ
5 V Range	Cm_____ Ci_____	±0.15		20.	pF
5 V Range	Ri_____	±0.003	0.985	1.015	MΩ

Table 10.3.5e Input Impedance - 50 Ω - Channel 1

Measurement Description	Measurement Data	Estimated Measurement Uncertainty	Specification Limits Min.	Max.	Units
5 mV Range	______	±0.003	49.50	50.50	Ω
10 mV Range	______	±0.003	49.50	50.50	Ω
20 mV Range	______	±0.003	49.50	50.50	Ω
50 mV Range	______	±0.003	49.50	50.50	Ω
100 mV Range	______	±0.003	49.50	50.50	Ω
0.20 V Range	______	±0.003	49.50	50.50	Ω
0.50 V Range	______	±0.003	49.50	50.50	Ω
1 V Range	______	±0.003	49.50	50.50	Ω
2 V Range	______	±0.003	49.50	50.50	Ω
5 V Range	______	±0.003	49.50	50.50	Ω

Table 10.3.5f Input Impedance - 50 Ω - Channel 2

Measurement Description	Measurement Data	Estimated Measurement Uncertainty	Specification Limits Min.	Max.	Units
5 mV Range	____________	±0.003	49.50	50.50	Ω
10 mV Range	____________	±0.003	49.50	50.50	Ω
20 mV Range	____________	±0.003	49.50	50.50	Ω
50 mV Range	____________	±0.003	49.50	50.50	Ω
100 mV Range	____________	±0.003	49.50	50.50	Ω
0.20 V Range	____________	±0.003	49.50	50.50	Ω
0.50 V Range	____________	±0.003	49.50	50.50	Ω
1 V Range	____________	±0.003	49.50	50.50	Ω
2 V Range	____________	±0.003	49.50	50.50	Ω
5 V Range	____________	±0.003	49.50	50.50	Ω

10.3.6 Vertical Channel Risetime

Specification:

The risetime of each vertical input channel shall not exceed 3.5 nanoseconds with and without the probes attached when measured between the 10 and 90 percent points of a step response that is at least 6 cm high at 5 mV/division.

Equipment:

Items	Model
Pulse Generator	Picosecond Pulse Labs Model 2700 Pulse Generator or equivalent
Male SMA to female N adapter	
Male N to Female BNC adapter	
Two 12" Coaxial Cables (male BNC connectors)	
20dB Attenuator	Weinschel Engineering Model 2-20 or equivalent
10:1 Voltage Divider Probes with BNC tip adapters	Supplied by Oscilloscope Manufacturer

Procedure:

1. Set the attenuator in the pulse generator for maximum attenuation. Use the 12 inch cable to connect the generator to Channel 1 of the storage oscilloscope, via the 20 dB attenuator. (Connect the attenuator directly to the BNC scope connector.) Refer to figure 10.3.6a.

2. Set the range of both oscilloscope channels to 5 mV/div and the sweep speed to 10 ns/div. or faster. Set the input coupling to dc 50 Ω ON. Employ internal triggering.

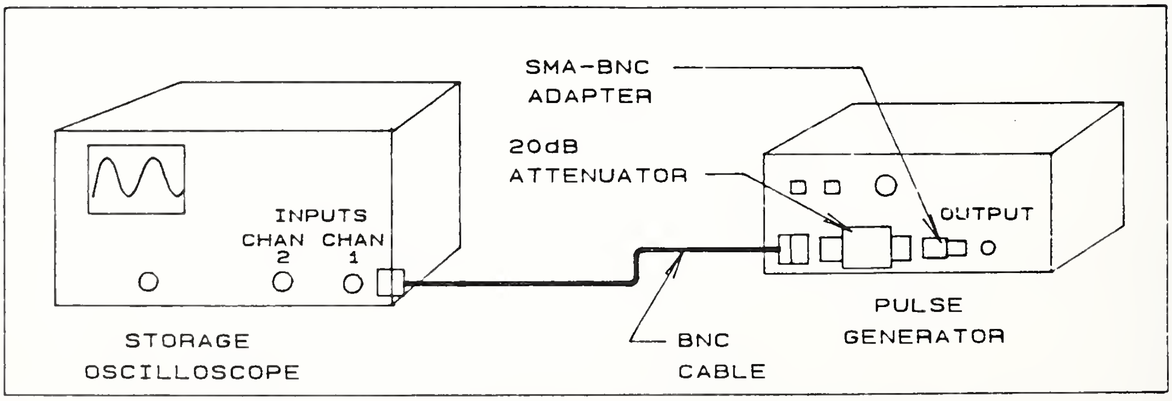


Figure 10.3.6a Test setup for measuring the vertical channel rise time without a probe

3. Adjusting the dc offset of the oscilloscope and the attenuator of the pulse generator, align the base line and top line of the pulse for coincidence with the - 3 division and + 3 division horizontal graticule lines, respectively.

4. Note that the 10% point on the pulse transition is 3 minor divisions above the base line, and that the 90% point on the pulse transition is 3 minor divisions below the top line.

5. Using the cursors in the delta time mode, adjust the positions of the cursors so that they pass through the 10% and 90% points of the pulse transition. Record the readout in table 10.3.6a.

6. Connect the generator, via the attenuator, to Channel 2, and repeat steps 3, 4, and 5.

7. Replace the cable and attenuator with a 10:1 voltage divider probe attached to each input channel of the oscilloscope, as shown in figure 10.3.6b. Be sure to use the BNC probe tip adapters. Set the ranges of both oscilloscope channels to 50 mV/div (maximum sensitivity using the probes), and the sweep speed should be set to 10 ns/div or faster. Set the input coupling for each channel to dc 50 Ω OFF.

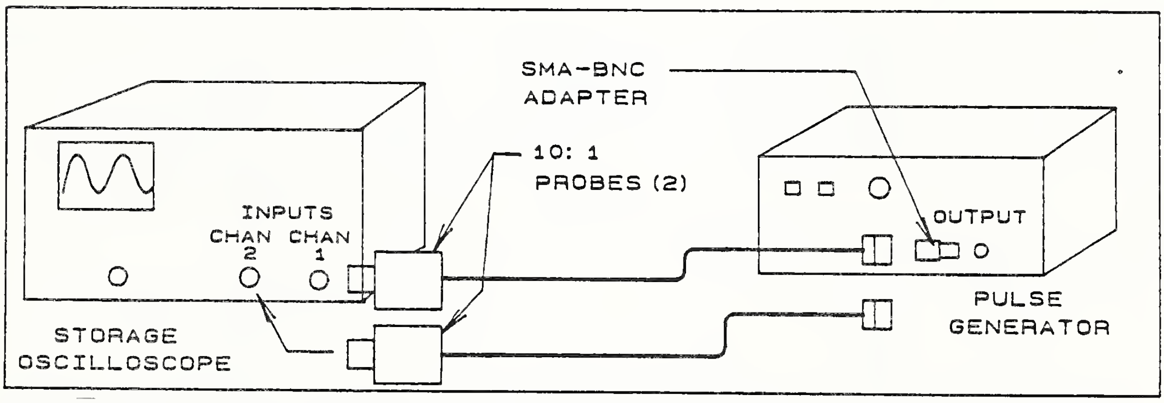


Figure 10.3.6b Test setup for measuring the vertical channel rise time with a probe

8. Connect the probe for Channel 1 to the pulse generator and repeat steps 3, 4 and 5. Record scope readouts into table 10.3.6b.

9. Next, connect the probe for Channel 2 to the generator and repeat steps 3, 4 and 5. Record scope readouts into table 10.3.6b.

Table 10.3.6a Vertical Channel Rise Time without Probe

Channel No.	Measured Rise Time (μs)	Estimated Measurement Uncertainty	Specification Limit (ns)
1		±1 ns	Not more than 3.5ns
2		±1 ns	Not more than 3.5ns

Table 10.3.6b Vertical Channel Rise Time with Probe

Channel No.	Measured Rise Time (μs)	Estimated Measurement Uncertainty	Specification Limit (ns)
1		± 1 ns	Not more than 3.5ns
2		± 1 ns	Not more than 3.5ns

10.3 Vertical Section

10.3.7 Channel Separation (Isolation)

Specification:

The separation between the vertical input channels with both attenuators on the most sensitive range shall be not less than 50:1 at 100 MHz.

Equipment:

Items	Model
Sine-Wave Generator	Tektronix SG 503 Leveled Sine Wave Generator or equivalent
36" Coaxial Cable (91.4 cm) (male BNC Connectors)	Tektronix P/N 012-0482-00 or equivalent

Procedure:

1. Connect the test equipment as shown in figure 10.3.7 below. Use the 36" coaxial cable to connect the sine-wave generator output to Channel 2 of the storage oscilloscope. Initially, set the generator to 100 MHz and its amplitude to a minimum value.

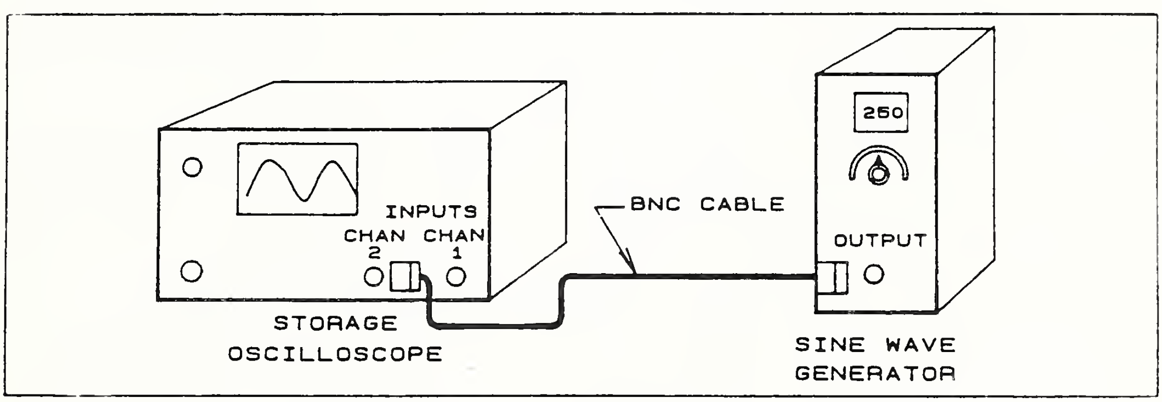


Figure 10.3.7 Test setup for measuring channel separation (isolation)

2. Set the range of both channels to 5 mV/div and the coupling for both channels to DC 50 Ω ON.

3. Adjust the output amplitude of the generator for a 30 mV p-p deflection on Channel 2.

4. Switch the channel selector to Channel 1 and use the cursors to measure the peak-to-peak amplitude of the sine wave fed through from Channel 2.

5. Enter the amplitude measured in step 4 in the first row of table 10.3.7.

6. Connect the output of the sine-wave generator to Channel 1 of the oscilloscope. Adjust the generator amplitude to obtain a 30 mV p-p deflection on Channel 1.

7. Switch the channel selector to Channel 2 and use the cursors to measure the peak-to-peak amplitude of the sine wave fed through from the other Channel 1.

8. Enter the amplitude measured in step 7 in the second row of table 10.3.7.

Table 10.3.7 Measurement of Channel Separation (Isolation)

30mV P-P Applied to:	P-P Voltage Fed Through To:	Estimated Measurement Uncertainty	Specification Limit (P-P)
Channel 2	Channel 1 ________ mV	± 0.25 mV	0.6mV
Channel 1	Channel 2 ________ mV	± 0.25 mV	0.6mV

10.3 Vertical Section

10.3.8 Common Mode Rejection Ratio (CMRR)

Specification:

The CMRR referenced to a 6 cm amplitude sine wave with both attenuators on the same calibrated range shall be not less than 10:1 at 50 MHz.

Equipment:

Items	Model
Sine-wave Generator	Tektronix SG 503 or equivalent
Two 36" Coaxial Cable (male BNC connectors)	Tektronix P/N 012-0482-00 or equivalent
Signal Splitter	NIST Supplied

Procedure:

1. Refer to figure 10.3.8. Set the frequency of the sine-wave generator to 50 MHz and its amplitude to a minimum value. Connect the signal splitter directly to the generator output, and use the cables to connect the signal splitter to the two inputs of the oscilloscope.

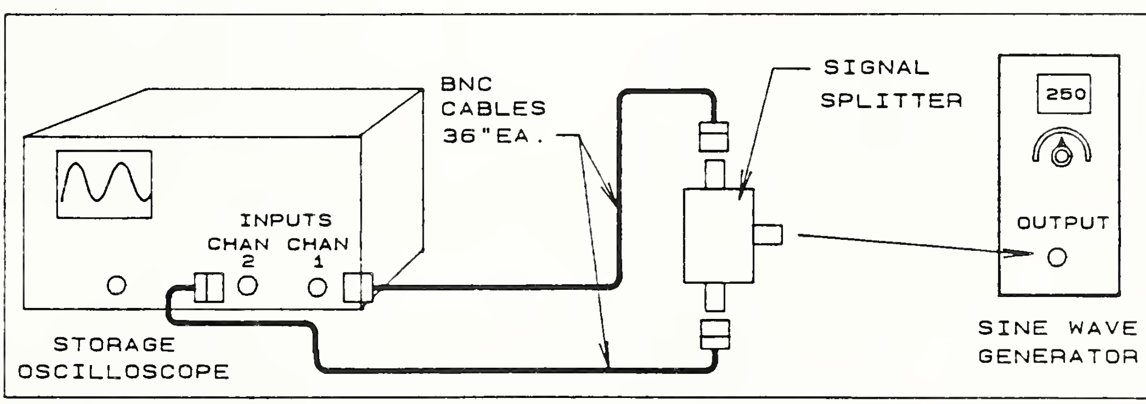


Figure 10.3.8 Test setup for measuring the common mode rejection

2. Set the range of both channels to 10 mV/div and the coupling for both channels to dc 50 Ω ON.

3. Adjust the generator for a displayed amplitude of 60 mV p-p. Observe the waveform on first one channel and then the other. The observed amplitude should be essentially the same on both channels.

3. Adjust the generator for a displayed amplitude of 60 mV p-p. Observe the waveform on first one channel and then the other. The observed amplitude should be essentially the same on both channels.

4. Set the channel selector for <u>addition</u> of the two channel inputs and invert only Channel 1.

5. Record the displayed p-p amplitude in row 1 of table 10.3.8.

6. Invert only Channel 2 and record the displayed p-p amplitude in row 2 of table 10.3.8.

Table 10.3.8 Measurement of Common Mode Rejection Ratio (CMRR)

Configuration	Displayed P-P Amplitude	Estimated Measurement Uncertainty	Specification Limit (P-P)
Channel 1 Inverted	____________ mV	± 1 mV	6 mV
Channel 2 Inverted	____________ mV	± 1 mV	6 mV

10.3 Vertical Section

10.3.9 Direct Current Drift

Specification:

The CRT trace drift of each vertical channel at the 10 mV per division setting shall not exceed 0.1 cm per hour at all impedance settings.

Equipment:

Items	Model
Clock	General Electric 2908 or equivalent

Procedure:

1. Set the controls of the storage oscilloscope to the default values given in NOTES, Item 4, p.1. Change the following controls from the default values to that shown below.

   Vertical Controls (both channels)
   VOLTS/DIV 10 mV

2. Assure that the sweep, on both vertical channels, is coincident with the horizontal centerline of the screen. Disregard small noise pulses that may be present on the trace. Do not connect any cables to the vertical input channels.

3. Record the start time on the clock in table 10.3.9.

4. After one hour, read and record the stop time and the position drift of the beam on both channels relative to the centerline of the screen.

5. Change the following controls from the default values to that shown below.

   Vertical Controls (both channels)
   IMPEDANCE 50 Ω

6. Assure that the sweep, on both vertical channels, is coincident with the horizontal centerline of the screen. Disregard small noise pulses that may be present on the trace. Do not connect any cables to the vertical input channels.

7. Record the clock start time in table 10.3.9.

8. After one hour, read and record the stop time and the position drift of the beam on both channels relative to the centerline of the screen.

Table 10.3.9 Direct Current Drift

Measurement Description	Measurement Data	Estimated Measurement Uncertainty	Specification Limits Min.	Max.	Units
Start Time	______________				
Ending Time	______________				
Drift - 1 MΩ Channel 1	______________	±0.05		0.1	cm
Drift - 1 MΩ Channel 2	______________	±0.05		0.1	cm
Start Time	______________				
Ending Time	______________				
Drift - 50 Ω Channel 1	______________	±0.05		0.1	cm
Drift - 50 Ω Channel 2	______________	±0.05		0.1	cm

10.3 Vertical Section

10.3.10 Delay Circuitry or Equivalent

Specification:

The equipment shall be capable of displaying the entire leading edge of an internally triggered 0.7 nsec or faster risetime 10 MHz square wave of one cm amplitude at 5 mV per division.

Equipment:

Items	Model
Pulse Generator	Picosecond Pulse Labs Model 2700 or equivalent
Female N to SMA Male Adapter	Pasternack PE9082 or equivalent
Male N to Female BNC Adapter	Pomona 3288 or equivalent
Two 12" Coaxial Cable (male BNC connectors)	Pomona 2249-C-12
20 dB Attenuator	Weinschel Engineering, Model 2-20 or equivalent
SMA Male to BNC Female Adapter	Pasternack PE 9074 or equivalent

Procedure:

NOTE: A pulse generator with 0.3 ns rise time and 200 ns pulse length is used instead of a square wave generator with 0.7 ns rise time (not available). The 20 dB attenuator is used to decrease the generator pulse amplitude to 5 mV.

1. Set the attenuator in the pulse generator for maximum attenuation. Use the 12 inch cable to connect the generator to Channel 1 of the scope, via the 20 dB attenuator. (Connect the attenuator directly to the BNC scope connector.) Refer to figure 10.3.10

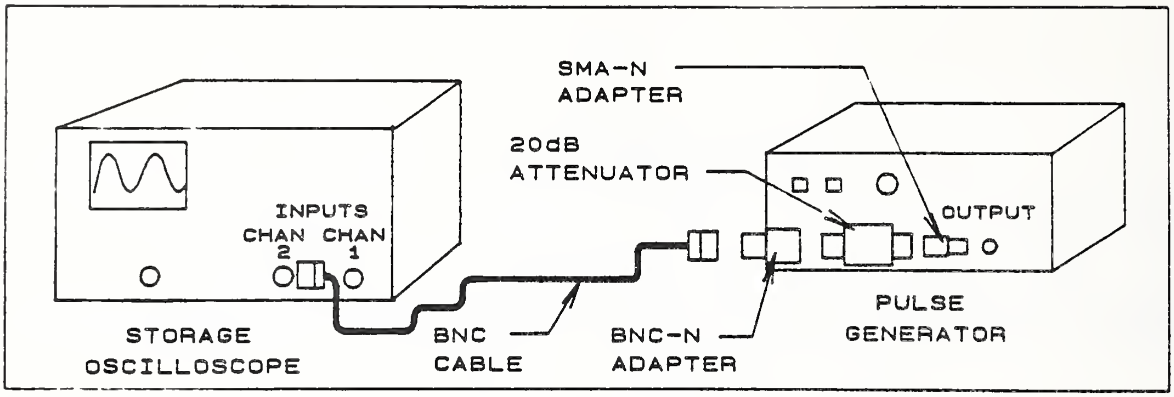


Figure 10.3.10 Test setup for measuring the delay circuitry or equivalent

2. Set the range of both oscilloscope channels to 5 mV/div and the sweep speed to 10 ns/div or faster. Set the input coupling to dc 50 Ω ON. Employ internal triggering.

3. Adjust the pulse generator attenuator for approximately 1 division of deflection by the pulse.

4. Adjust the trigger controls of the scope for displaying as much of the leading edge as possible. Check to see that at least 90% of the pulse transition is displayed.

5. Indicate in table 10.3.10 how well the leading edge of the pulse is displayed using Channel 1.

6. Connect the generator, via the attenuator, to Channel 2, and repeat steps 3 and 4.

7. Indicate in table 10.3.10 how the leading edge of the pulse is displayed using Channel 2.

Table 10.3.10 Delay Circuitry or Equivalent

	Channel 1		Channel 2	
	Yes	No	Yes	No
Does Oscilloscope trigger satisfactorily on input Pulse?				
Is at least 90% of leading edge of pulse displayed?				

10.3.11 Dynamic Range

Specification:

Overshoot and undershoot of each vertical channel shall not exceed those measured at center screen by more than 1.0 percent when:

a. *The top of 2 cycles of a 6 cm displayed symmetrical square wave is positioned on the bottom graticule line.*

b. *The bottom of the same 6 cm displayed symmetrical square wave is positioned on the top graticule line.*

Equipment:

Items	Model
Pulse Generator	Hewlett-Packard Model 8082A or equivalent
36" Coaxial Cable (male BNC connectors)	Pomona BNC-C-36 or equivalent

Procedure:

1. Connect the output of the pulse generator to Channel 1 of the storage oscilloscope as shown in figure 10.3.11a.

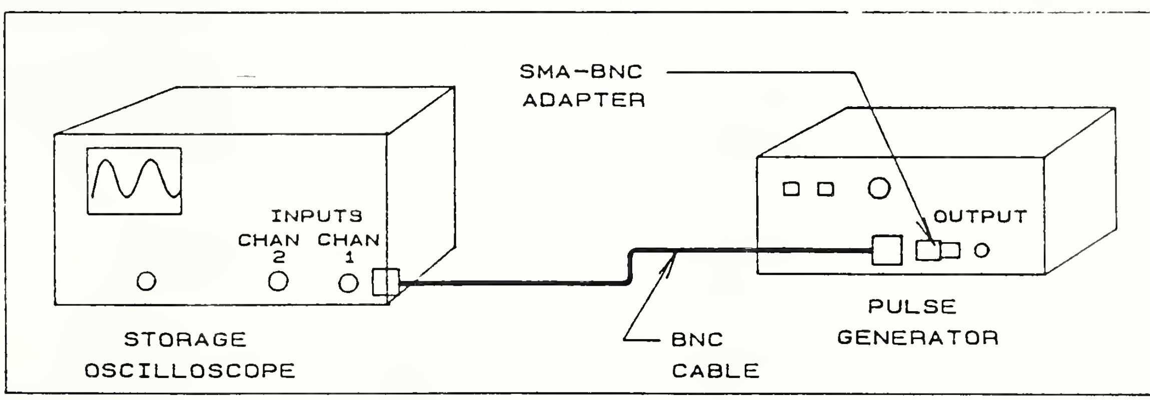


Figure 10.3.11a Test setup for measuring dynamic range

2. Set the pulse generator controls for a square wave pulse output and a range of 1 V. Use the uncomplemented output and set the polarity switch to "Negative." Select a frequency of approximately 1 MHz.

3. Set the range of both oscilloscope channels to 50 mV/div. and select a sweep speed of 200 ns/div. Set the input coupling for both channels to dc 50 Ω ON. Center the horizontal trace with no signal applied.

4. Adjust the amplitude and offset of the generator for ±3 divisions of deflection (300 mV p-p).

5. Use the cursors in the delta voltage mode to measure the peak-to-peak distortion at the top of the waveform, as illustrated in figure 10.3.11b. Record the readout of the cursor spacing into the "N" data column of the "Top of Waveform" section of Table 10.3.11a.

6. Offset the cursor spacing an arbitrary amount, and then reposition the cursors as before. Record the new readout into the next data row in column N.

7. Repeat step 6 three more times and use the calculator to obtain the average (Av = N) of the five readings and the standard deviation, s_N.

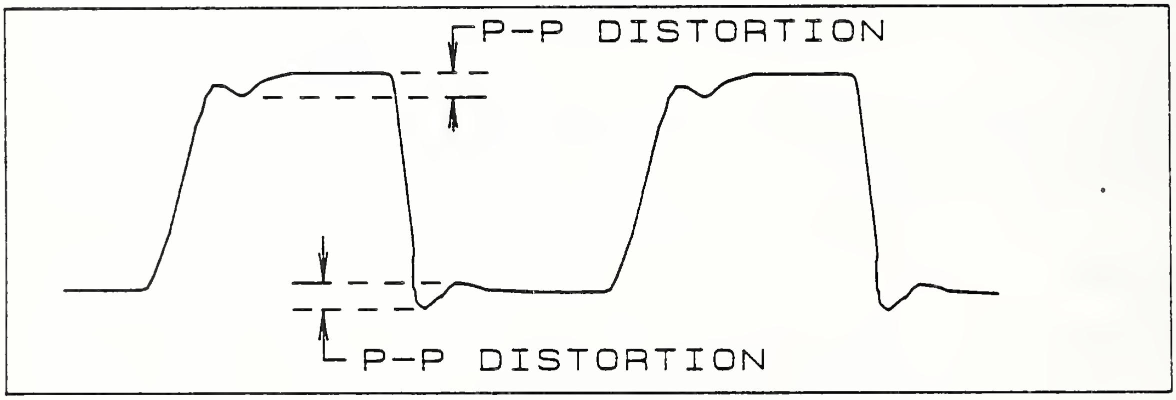


Figure 10.3.11b Illustration of P-P distortion for overshoot and undershoot

8. Adjust the offset of the generator so that the top of the waveform is approximately 3 cm below the center horizontal graticule line. Use the cursors to measure the peak-to-peak distortion of the top of the waveform. Record the readout into the "D" data column of the "Top of Waveform" section of Table 10.3.11a.

9. Repeat this measurement four more times (always offsetting and repositioning the cursors), and record these readouts into column D.

10. Obtain the average of these five readings (Av = D) and the standard deviation, s_D. Next, enter the quantity N-D into the third column, and the quantity $(s_N^2 + s_D^2)^{1/2}$ into the fourth column.

11. Adjust the offset of the pulse generator for ±3 division of deflection. Use the cursors to measure the p-p distortion at the bottom of the waveform, as illustrated in figure 10.3.11b. Record the readout into the "N" column of the "Bottom of Waveform" section of Table 10.3.11a.

12. Repeat this measurement four more times, and also record these readouts into the "N" column. Calculate the average of these five readings (Av = N) and the standard deviation, s_N.
13. Adjust the offset of the generator so that the bottom of the waveform is approximately 3 divisions above the center horizontal graticule line. Use the cursors to measure the p-p distortion of the bottom of the waveform. Record the readout into the "D" data column of the "Bottom of Waveform" section of Table 10.3.11a.

14. Repeat this measurement four more times and record these readouts into column D. Obtain the average of these five readings (Av = D) and the standard deviation, s_D. Next enter the quantity N-D into the third column and the quantity $(s_N^2 + s_D)^{½}$ into the fourth column.

15. Check to see that the N-D quantities for the top and bottom of the waveform are within the specification limits.

16. Disconnect the coaxial cable from Channel 1 and connect to Channel 2 of the storage oscilloscope and repeat steps 3 through 15, using Table 10.3.11b instead of Table 10.3.11a.

Table 10.3.11a Dynamic Range Measurement for Channel 1

Top of Waveform					
Peak-to-peak distortion N (Normal Position) (mV)	Peak-to-peak distortion D (-3 Divisions Positions) (mV)	Difference in P-P Distortion N-D	Uncer-tainty in N-D $(s_N^2+s_D^2)^{1/2}$	Specification Limit in N-D Min	Specification Limit in N-D Max
1)______ 2)______ 3)______ 4)______ 5)______ Av______	1)______ 2)______ 3)______ 4)______ 5)______ Av______	______ mV	______mV	-3 mV	+3 mV

Bottom of Waveform					
Peak-to-peak distortion N (Normal Position) (mV)	Peak-to-peak distortion D (+3 Divisions Positions) (mV)	Difference in P-P Distortion N-D	Uncer-tainty in N-D $(s_N^2+s_D^2)^{1/2}$	Specification Limit in N-D Min	Specification Limit in N-D Max
1)______ 2)______ 3)______ 4)______ 5)______ Av______	1)______ 2)______ 3)______ 4)______ 5)______ Av______	______ mV	______mV	-3 mV	+3 mV

Table 10.3.11b Dynamic Range Measurement for Channel 2

Top of Waveform					
Peak-to-peak distortion		Difference in P-P Distortion N-D	Uncer-tainty in N-D $(s_N^2+s_D^2)^{1/2}$	Specification Limit in N-D	
N (Normal Position) (mV)	D (-3 Divisions Positions) (mV)			Min	Max
1) ____ 2) ____ 3) ____ 4) ____ 5) ____ Av ____	1) ____ 2) ____ 3) ____ 4) ____ 5) ____ Av ____	____ mV	____ mV	-3 mV	+3 mV

Bottom of Waveform					
Peak-to-peak distortion		Difference in P-P Distortion N-D	Uncer-tainty in N-D $(s_N^2+s_D^2)^{1/2}$	Specification Limit in N-D	
N (Normal Position) (mV)	D (+3 Divisions Positions) (mV)			Min	Max
1) ____ 2) ____ 3) ____ 4) ____ 5) ____ Av ____	1) ____ 2) ____ 3) ____ 4) ____ 5) ____ Av ____	____ mV	____ mV	-3 mV	+3 mV

10.3 Vertical Section

10.3.12 X-Y Display

Specification:

The equipment shall have an x-y display capability through the vertical input channels.

Equipment:

Items | Model

None

Procedure:

1. Read the instruction manual supplied with the storage oscilloscope to determine that the equipment has an X-Y capability through the vertical input channels. Record the compliance (or lack of compliance) of this specification in table 10.3.12.

Table 10.3.12 X-Y Display

Measurement Description	Measurement Data	Estimated Measurement Uncertainty	Specification Limits Min.	Specification Limits Max.	Units
X-Y through Channel 1?	____________	N/A	Yes		
X-Y through Channel 2?	____________	N/A	Yes		

10.3 Vertical Section

10.3.12.1 X-Y Display Bandwidth

Specification:

The Y axis bandwidth shall be the same as Channel A [called Channel 1 throughout]. The X axis -3 dB bandwidth shall be at least 3 MHz.

Equipment:

Items	Model
Sine-Wave Generator	Tektronix SG 503 or equivalent
BNC Male to BNC Male Coaxial Cable 36 inches (91.4 cm)	Tektronix P/N 012-0482-00 or equivalent
50 Ω Feedthrough Termination	Tektronix 011-0049-01 or equivalent

Procedure:

Part 1: Y-Axis bandwidth

1. Set the controls of the storage oscilloscope to the default values given in NOTES, Item 4, p.1. Change the following controls from the default values to that shown below. Note that some oscilloscopes require adjustment to both the vertical and sweep controls to obtain X-Y mode.

Vertical Controls	
VOLTS/DIV	1 V
MODE	To Display X-Y Mode
Sweep Controls	
HORIZONTAL DISPLAY	To Display X-Y Mode at a sensitivity of 1 V per division

2. Connect the output of the sine-wave generator to the Y input of the storage oscilloscope as shown in the figure below. Do not connect any cables to the X-input connector.

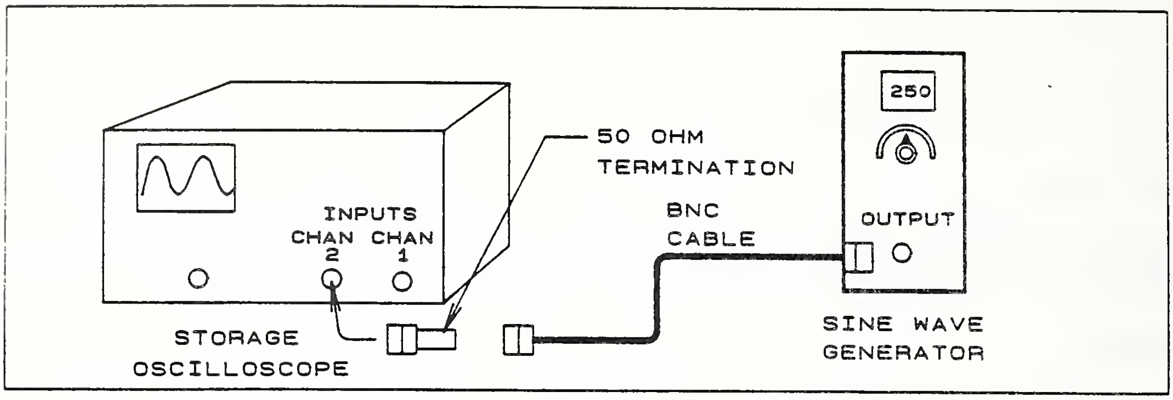


Figure 10.3.12.1a Test setup for the measurement of X-Y display bandwidth (Y-input)

3. Adjust the output level of the sine-wave generator to provide a 5 V peak-to-peak sine wave at 50 kHz.

4. Read and record the amplitude of the vertical line representing the input to the Y axis, Vry, in table 10.3.12.1. This value is the amplitude, in volts, at the reference frequency of 50 kHz.

5. Increase the frequency of the sine-wave generator to the bandwidth specified for Channel 1, nominally 100 MHz.

6. Read and record the amplitude of the vertical line representing the input to the Y axis, Vfy, in table 10.3.12.1. This value is the amplitude, in volts, at the full-bandwidth frequency of 100 MHz.

7. Calculate the ratio between the Y-axis response at the reference frequency and at full bandwidth according to the following formula:

$$Ry = 20 \log_{10} \frac{Vfy}{Vry}$$

Record the calculated value in table 10.3.12.1.

Part 2: X-Axis bandwidth

8. Connect the output of the sine-wave generator to the X input of the storage oscilloscope as shown in the figure below. Do not connect any cables to the Y-input connector.

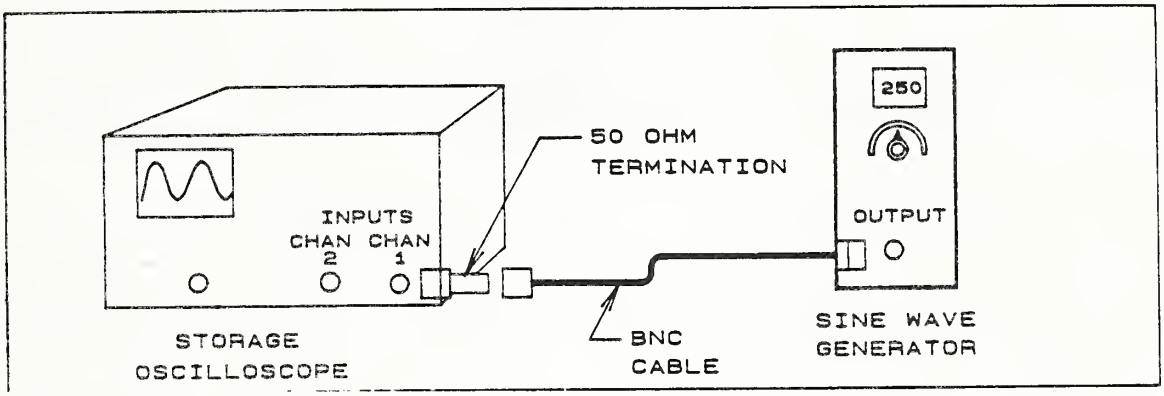


Figure 10.3.12.1b Test setup for the measurement of X-Y display bandwidth (X-input)

9. Adjust the output level of the sine-wave generator to provide a 5 V peak-to-peak sine wave at 50 kHz.

10. Read and record the amplitude of the vertical line representing the input to the X axis, Vrx, in table 10.3.12.1. This value is the amplitude, in volts, at the reference frequency of 50 kHz.

11. Increase the frequency of the sine-wave generator to the bandwidth specified for the X-axis, 3 MHz.

12. Read and record the amplitude of the vertical line representing the input to the X axis, Vfx, in table 10.3.12.1. This value is the amplitude, in volts, at the full-bandwidth frequency of 3 MHz.

13. Calculate the ratio between the X-axis response at the reference frequency and at full bandwidth according to the following formula:

$$Rx = 20 \log_{10} \frac{Vfx}{Vrx}$$

Record the calculated value in table 10.3.12.1.

Table 10.3.12.1 X-Y Display Bandwidth

Measurement Description	Measurement Data	Estimated Measurement Uncertainty	Specification Limits Min.	Max.	Units
Y-amplitude at 50 kHz, Vry	________	N/A (ratio measurement)			V p-p
Y-amplitude at 100 MHz, Vfy	________	±0.05			V p-p
Y-axis response (dB)	________	±0.086	-3		dB
X-amplitude at 50 kHz, Vrx	________				V p-p
X-amplitude at 3 MHz, Vfx	________	±0.05			V p-p
X-axis response (dB)	________	±0.086	-3		dB

10.3.12.2 X-Y Display Phase Difference

Specification:

Phase difference in the x-y display mode shall not be greater than 1 degree from DC to 1 MHz and increasing to no more than 3 degrees from 1 MHz to 2 MHz with both attenuators calibrated and in the 10 mV per division positions.

Equipment:

Items	Model
Sine-Wave Generator	Tektronix SG503 Leveled Sine Wave Generator or equivalent
Signal Splitter	NIST special fixture
Two 36" coaxial cables (male BNC connectors)	Tektronix P/N 012-0482-00 or equivalent

Procedure:

1. Connect the generator to X and Y channels, using the signal splitter as shown in figure 10.3.12a.

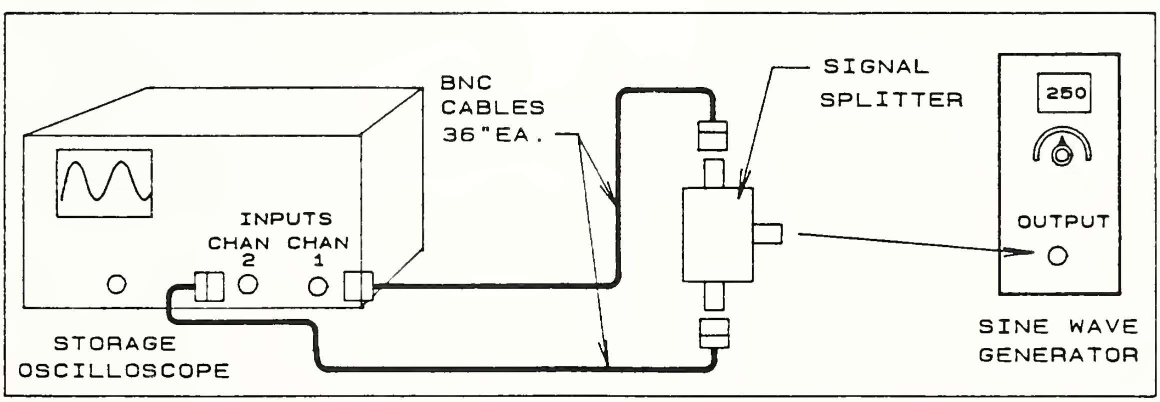


Figure 10.3.12.2a Test setup for measurement of display phase difference

2. Set the range of the two oscilloscope channels to 50 mV/div and set the coupling to dc 50 Ω ON. Set Channels 1 and 2 for X and Y operation.

3. Set the amplitude multiplier of the sine-wave generator to X.1 and the frequency to 1 MHz.

4. Adjust the output level of the sine-wave generator for a diagonal deflection of the magnitude shown in figure 10.3.12.2b. Note: An ellipse with a very small minor axis may be displayed instead of a line. However, the orientation will be the same as for the line shown.

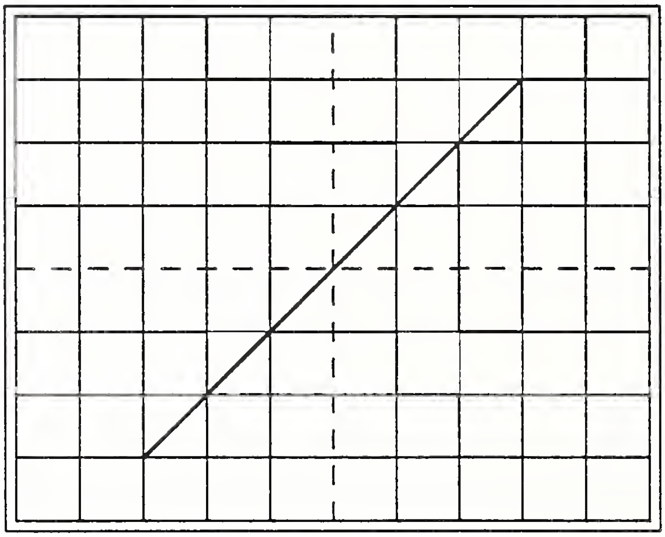


Figure 10.3.12.2b Display of the measurement of X-Y display phase difference, 1st step

5. Change the range of the X and Y channels to 10 mV/div. If sufficient phase difference exists between the channels, part of an ellipse, having a very small minor axis, will be displayed as shown in figure 10.3.12.2c. Note: The display showing nearly parallel lines results because only about one-fourth of the ellipse is on scale.

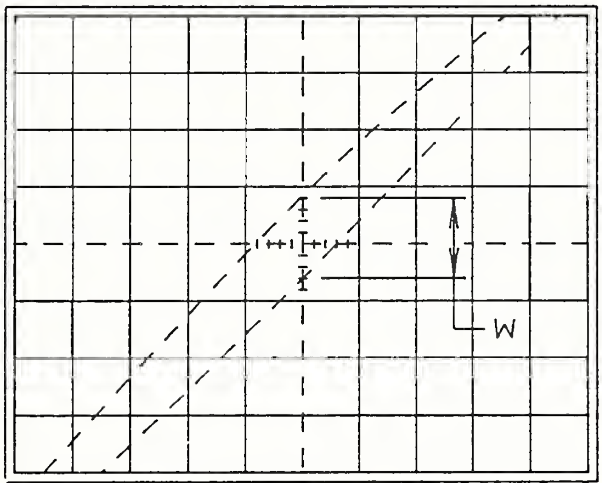


Figure 10.3.12.2c Display of the measurement of display phase difference, 2nd step. W is the measure of phase difference

6. Using the cursors in the delta voltage mode (yielding horizontal cursors), measure the vertical spacing between the displayed lines as shown in figure 10.3.12.2c. Record W in terms of minor divisions in table 10.3.12.

7. Change the generator frequency to 2 MHz and repeat steps 4, 5 and 6.

8. Compute the X-Y phase difference, in degrees, for each frequency by multiplying W by the factor 2.33. Record the results in column 3 of table 10.3.12.2.

Table 10.3.12.2 X-Y Display Phase Difference

Frequency	Ellipse Minor Axis (W)	X-Y Phase Difference	Estimated Measurement Uncertainty	Specification Limits Min	Max
1 MHz	________	________	± 0.7 Deg		1 Deg
2 MHz	________	________	± 0.7 Deg		3 Deg

10.3.12.3 X-Y Display Range

Specification:

The x-y display capability shall be over the full range of the vertical attenuators.

Equipment:

Items	Model
Meter Calibrator	Fluke Model 5101B or equivalent
BNC Male to BNC Male Coaxial Cable 36 inches (91.4 cm)	Tektronix P/N 012-0482-00 or equivalent
BNC Female to Banana Adapter	Pomona 1452 or equivalent
BNC "T" Adapter - Female, Male, Female	Pomona 3285 or equivalent
BNC Male to BNC Male Coaxial Cable 18 inches (45.7 cm)	Pomona BNC-B-18 or equivalent

Procedure:

1. Connect the equipment as shown below.

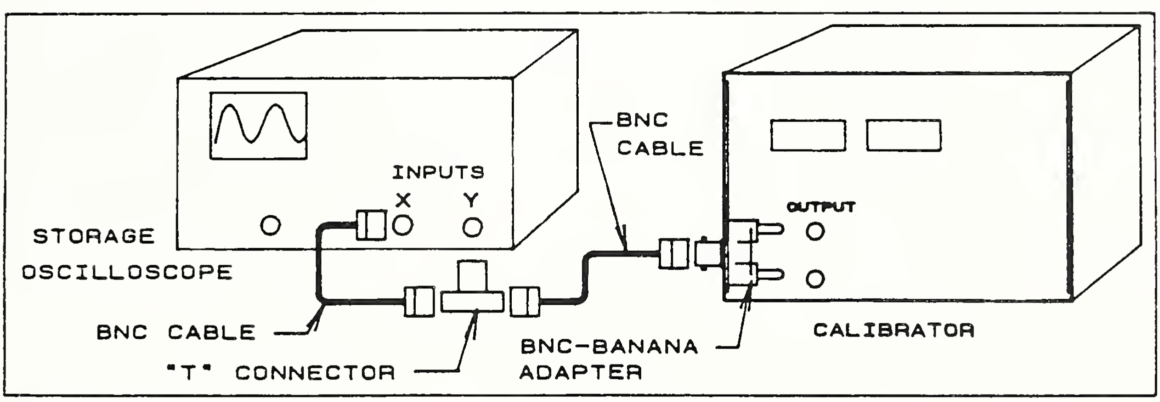


Figure 10.3.12.3 Test setup for demonstration of X-Y display range

2. Set the controls of the oscilloscope to the default values given in the NOTES, Item 4, p.1. Change the following controls from the default values to that shown below. Note that some oscilloscopes require adjustment to both the vertical and sweep controls to obtain X-Y mode.

Vertical Controls	
VOLTS/DIV	5 mV
MODE	To Display X-Y Mode
Sweep Controls	
HORIZONTAL DISPLAY	To Display X-Y Mode at a sensitivity of 5 mV per division

3. Adjust the range of the vertical X- and Y-input attenuators of the storage oscilloscope and the applied voltage, Va, from the meter calibrator in accordance with the values given in table 10.3.12.3. Set the output frequency of the meter calibrator to 1 kHz.

4. Assure that for each range, a display is produced on the storage oscilloscope that is a 45° line, representing equal values of X and Y voltage. Record the compliance of this specification by entering YES in table 10.3.12.3 for each X-Y attenuator setting. If the display does not comply with this specification, enter NO.

Table 10.3.12.3 X-Y Display Range.

Measurement Description	Measurement Data	Estimated Measurement Uncertainty	Specification Limits Min.	Max.	Units
5 mV Range Va = 12.5 mV	____________	N/A	Yes		
10 mV Range Va = 25 mV	____________	N/A	Yes		
20 mV Range Va = 50 mV	____________	N/A	Yes		
50 mV Range Va = 125 mV	____________	N/A	Yes		
100 mV Range Va = 250 mV	____________	N/A	Yes		
0.20 V Range Va = 0.50 V	____________	N/A	Yes		
0.50 V Range Va = 1.250 V	____________	N/A	Yes		
1 V Range Va = 2.500 V	____________	N/A	Yes		
2 V Range Va = 5.000 V	____________	N/A	Yes		
5 V Range Va = 12.500V	____________	N/A	Yes		

10.3 Vertical Section

10.3.13 Vertical Position and/or Equivalent Offset Capability

Specification:

The equipment shall provide a vertical position control/capability for each channel which provide a ground position range ±10 divisions.

Equipment:

Items	Model
Meter Calibrator	Fluke Model 5101B or equivalent
BNC Male to BNC Male Coaxial Cable 36 inches (91.4 cm)	Tektronix P/N 012-0482-00 or equivalent
BNC Female to Banana Adapter	Pomona 1452 or equivalent

Procedure:

1. Connect the equipment as shown below.

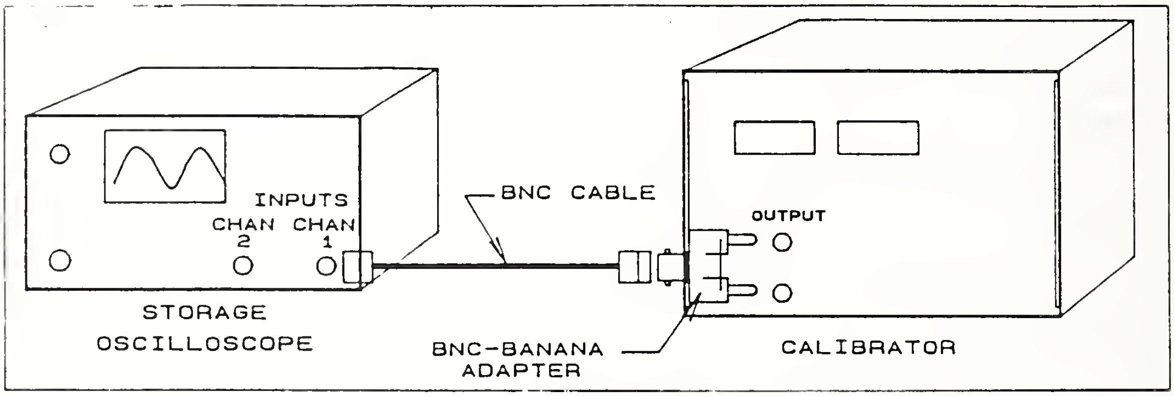


Figure 10.3.13 Test setup for demonstration of vertical position and/or equivalent offset capability

2. Set the controls of the oscilloscope to the default values given in the NOTES, Item 4, p.1.

3. Connect the cable and adapter between the OUTPUT HI and LO connector of the meter calibrator and the CHANNEL 1 input of the storage oscilloscope.

4. Place the vertical position control in the ground position range (trace should not be offset vertically).

5. Assure that the trace is coincident with the horizontal centerline marked on the CRT.

5. Assure that the trace is coincident with the horizontal centerline marked on the CRT.

6. Adjust the meter calibrator for an output of +10 V dc.

7. Use the vertical position control to reposition the trace on the horizontal centerline marked on the CRT. Record the compliance (or lack of compliance) of this specification in table 10.3.13.

8. Place the vertical position control in the ground position range (trace should not be offset vertically).

9. Assure that the trace is coincident with the horizontal centerline marked on the CRT.

10. Adjust the meter calibrator for an output of -10 V dc.

11. Use the vertical position control to reposition the trace on the horizontal centerline marked on the CRT. Record the compliance (or lack of compliance) of this specification in table 10.3.13.

12. Connect the cable and adapter between the OUTPUT HI and LO connector of the meter calibrator and the CHANNEL 2 input of the storage oscilloscope.

13. Repeat steps 4 through 11.

Table 10.3.13 Vertical Position and/or Equivalent Offset Capability

Measurement Description	Measurement Data	Estimated Measurement Uncertainty	Specification Limits Min.	Max.	Units
Channel 1 pos. at +10 V?	________	N/A	Yes		
Channel 1 pos. at -10 V?	________	N/A	Yes		
Channel 2 pos. at +10 V?	________	N/A	Yes		
Channel 2 pos. at -10 V?	________	N/A	Yes		

10.3.13.1 Coupling

Specification:

Coupling controls for each vertical channel shall be provided. The coupling controls shall have an AC, DC and a ground position. When in the ground position, the input signal circuit shall be open and the input circuit to the input amplifier shall be grounded.

Equipment:

Items	Model
Meter Calibrator	Fluke Model 5101B or equivalent
BNC Male to BNC Male Coaxial Cable 36 inches (91.4 cm)	Tektronix P/N 012-0482-00 or equivalent
BNC Female to Banana Adapter	Pomona 1452 or equivalent

Procedure:

1. Connect the equipment as shown below.

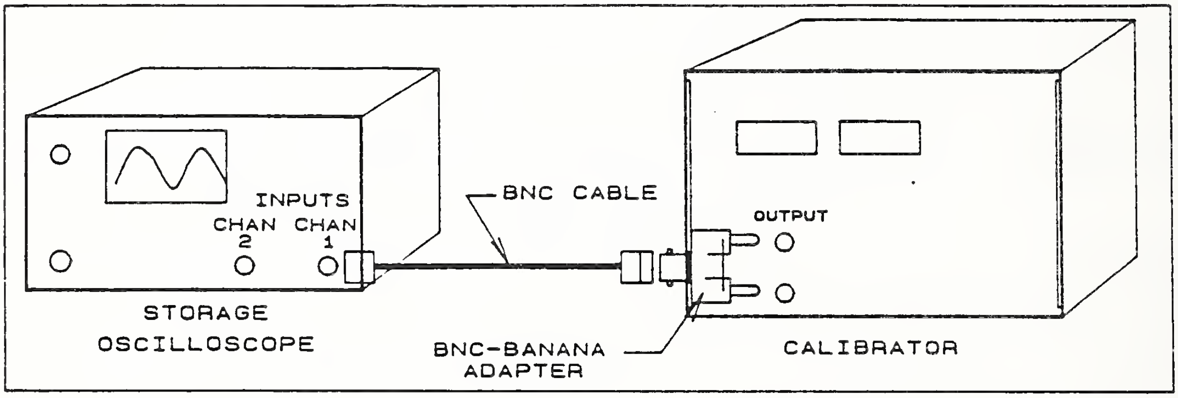


Figure 10.3.13.1 Test setup for demonstration of vertical position

2. Set the controls of the oscilloscope to the default values given in the NOTES, Item 4, p.1.

3. Connect the cable and adapter between the OUTPUT HI and LO connector of the meter calibrator and the CHANNEL 1 input of the storage oscilloscope.

4. Place the coupling control in the ground position.

5. Assure that the trace is coincident with the horizontal centerline marked on the CRT.

6. Adjust the meter calibrator for an output of +10 V dc.

7. Assure that the trace does not move vertically indicating that the input signal circuit is open. Record the compliance (or lack of compliance) of this specification in table 10.3.13.1.

8. Set the output voltage of the meter calibrator to zero.

9. Place the coupling control in the AC position.

10. Adjust the meter calibrator for an output of +10 V dc.

11. The trace will move vertically (probably off the CRT display area) and then settle on the horizontal centerline of the CRT indicating that the coupling is set to AC. Record the compliance (or lack of compliance) of this specification in table 10.3.13.1.

12. Set the output voltage of the meter calibrator to zero.

13. Place the coupling control in the DC position.

14. Adjust the meter calibrator for an output of +4 V dc.

15. Assure that the trace moves vertically four divisions indicating that the coupling is set to DC. Record the compliance (or lack of compliance) of this specification in table 10.3.13.1.

16. Connect the cable and adapter between the OUTPUT HI and LO connector of the meter calibrator and the CHANNEL 1 input of the storage oscilloscope.

17. Repeat steps 4 through 15 for CHANNEL 2.

Table 10.3.13.1 Coupling

Measurement Description	Measurement Data	Estimated Measurement Uncertainty	Specification Limits Min.	Max.	Units
Gnd coupling complies-CH 1?	______________	N/A	Yes		
AC coupling complies-CH 1?	______________	N/A	Yes		
DC coupling complies-CH 1?	______________	N/A	Yes		
Gnd coupling complies-CH 2?	______________	N/A	Yes		
AC coupling complies-CH 2?	______________	N/A	Yes		
DC coupling complies-CH 2?	______________	N/A	Yes		

10.3 Vertical Section

10.3.14 Display Mode

Specification:

The mode selector control(s) shall provide the capabilities of a through e below:

a. *Channel A only [referred to as Channel 1]*

b. *Channel B only [referred to as Channel 2]*

c. *Both Channel A [1] and Channel B [2] are displayed (equivalent to alternate or chop).*

d. *Algebraic. This mode shall display the instantaneous algebraic sum of Channel A [1] and B [2].*

e. *X-Y Display. This mode shall permit operation of the vertical channels in an X-Y display mode.*

Equipment:

Items	Model
Meter Calibrator	Fluke Model 5101B or equivalent
BNC Male to BNC Male Coaxial Cable 36 inches (91.4 cm)	Tektronix P/N 012-0482-00 or equivalent
BNC Female to Banana Adapter	Pomona 1452 or equivalent
BNC "T" Adapter - Female, Male, Female	Pomona 3285 or equivalent
BNC Male to BNC Male Coaxial Cable 18 inches (45.7 cm)	Pomona BNC-B-18 or equivalent

Procedure:

1. Connect the equipment as shown below.

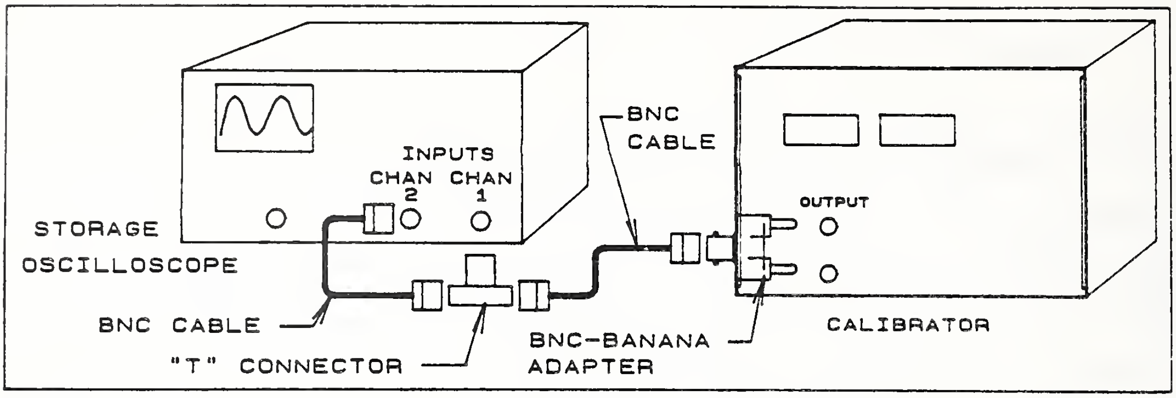


Figure 10.3.14a Test setup for demonstration of display mode - channels 1 and 2

2. Adjust the output voltage of the meter calibrator to provide 2.828 V rms (8 V peak-to-peak) at a frequency of 1 kHz.

3. Change the following controls from the default values to that shown below.

Vertical Controls	
VOLTS/DIV - A Input	1 V/div
- B Input 2 V/div	
MODE	To display Channel 1

4. Assure that a series of sine waves are displayed that are 8 divisions high. Record the compliance (or lack of compliance) of this specification in table 10.3.14.

5. Change the following controls to that shown below.

Vertical Controls	
MODE	To display Channel 2

6. Assure that a series of sine waves are displayed that are 4 divisions high. Record the compliance (or lack of compliance) of this specification in table 10.3.14.

7. Change the following controls to that shown below.

Vertical Controls	
MODE	To display both Channel 1 and Channel 2 in chopped mode

8. Assure that two sine waves are displayed, one that is 4 divisions high, and the other that is 8 divisions high. Furthermore, assure that the traces displaying the sine waves cross the screen at the same time not Record the compliance (or lack of compliance) of this specification in table 10.3.14.

9. Adjust the output voltage of the meter calibrator to provide 0.707 V rms (2 V peak-to-peak) at a frequency of 1 kHz

10. Change the following controls to that shown below.

Vertical Controls	
VOLTS/DIV - A Input	2 V/div
- B Input 1 V/div	
MODE	Algebraic display mode

11. Assure that one sine wave is displayed that is 3 divisions high. Record the compliance (or lack of compliance) of this specification in table 10.3.14.

12. If necessary, reconnect the equipment to obtain an X-Y display, as shown below.

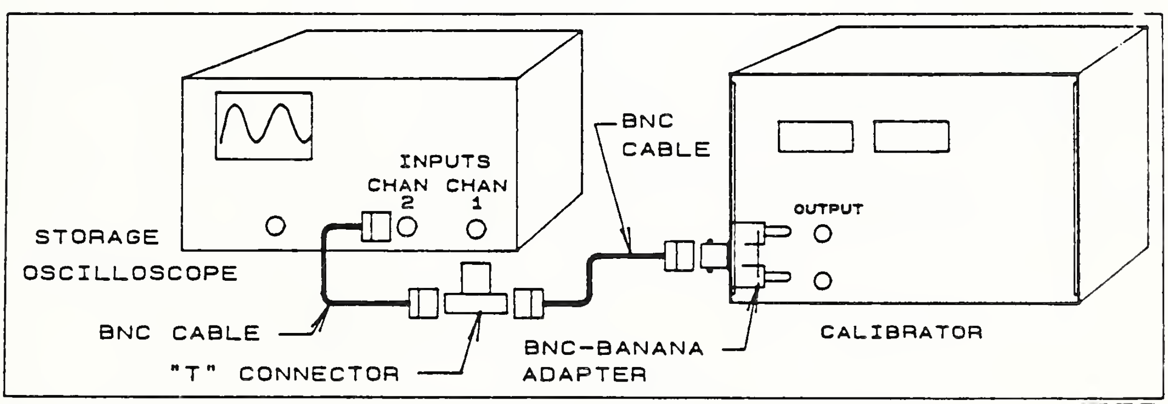


Figure 10.3.14b Test setup for demonstration of display mode - X-Y display mode

13. Change the following controls to that shown below.

Vertical Controls
VOLTS/DIV - A Input 1 V/div
- B Input 1 V/div
MODE X-Y display mode
Sweep Controls
HORIZONTAL DISPLAY X-Y Mode [2]

14. Assure that a display is produced on the storage oscilloscope that is a 45° line, representing an equal values of X and Y voltage. Record the compliance (or lack of compliance) of this specification in table 10.3.14.

Table 10.3.14 Display Mode

Measurement Description	Measurement Data	Estimated Measurement Uncertainty	Specification Limits Min.	Max.	Units
One trace 8 div high?	____________	N/A	Yes		
One trace 4 div high?	____________	N/A	Yes		
2 traces	____________	N/A	Yes		
One sine wave 3 div high?	____________	N/A	Yes		
45° line?	____________	N/A	Yes		

---

[2] Some Oscilloscopes may require adjustment to the horizontal function to obtain an X-Y display.

10.3 Vertical Section

10.3.15 Polarity Inverter

Specification:

A control shall be provided to invert the waveform being processed through at least one of the channels.

Equipment:

Items	Model
Meter Calibrator	Fluke Model 5101B or equivalent
BNC Male to BNC Male Coaxial Cable 36 inches (91.4 cm)	Tektronix P/N 012-0482-00 or equivalent
BNC Female to Banana Adapter	Pomona 1452 or equivalent
BNC "T" Adapter - Female, Male, Female	Pomona 3285 or equivalent
BNC Male to BNC Male Coaxial Cable 18 inches (45.7 cm)	Pomona BNC-B-18 or equivalent

Procedure:

1. Connect the equipment as shown below.

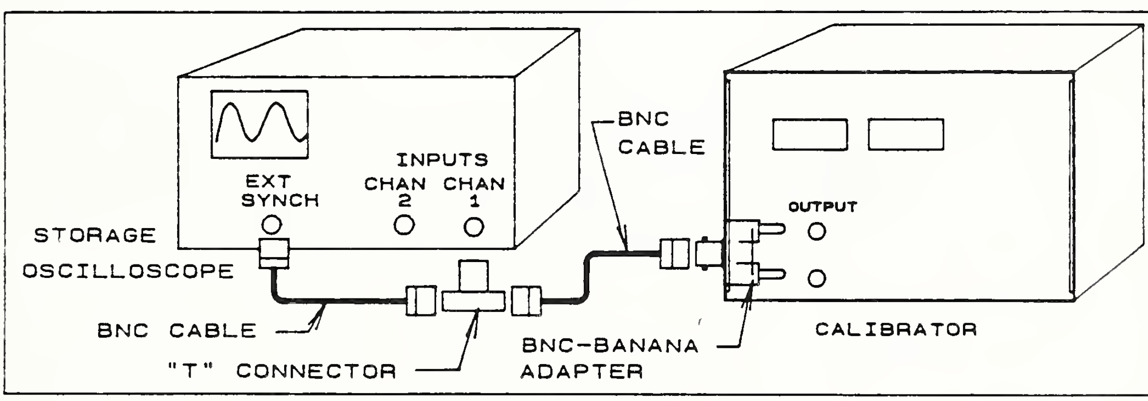


Figure 10.3.15 Test setup for demonstration of polarity inverter

2. Adjust the output voltage of the meter calibrator to provide 0.707 V rms (2 V peak-to-peak) at a frequency of 1 kHz.

3. Change the following controls from the default values to that shown below.

Vertical Controls	
VOLTS/DIV - A Input	1 V/div
MODE	To display Channel 1
Triggering Controls	
SOURCE	External
TRIGGER MODE	Normal

4. Assure that a series of approximately ten sine waves are displayed that are two divisions high. If necessary, adjust the trigger level slightly to obtain a stable display such that the sine wave displayed on the left-hand side of the screen has an initial positive slope from the baseline. Record the compliance (or lack of compliance) of this specification in table 10.3.15.

5. Change the following controls from the default values to that shown below.

Vertical Control	
INVERT	On

6. Assure that the series of sine waves has been inverted and that now the sine wave displayed on the left-hand side of the screen has an initial negative slope from the baseline. If necessary, adjust the trigger level slightly to obtain a stable display. Record the compliance (or lack of compliance) of this specification in table 10.3.15.

Table 10.3.15 Polarity Inverter

Measurement Description	Measurement Data	Estimated Measurement Uncertainty	Specification Limits Min.	Specification Limits Max.	Units
Initial Slope Positive (+)	____________	N/A	Yes		
Initial Slope Negative (-)	____________	N/A	Yes		

10.3 Vertical Section

10.3.16 Direct Current Balance

Specification:

A front panel or operator accessible DC balance control shall not be provided. The vertical channels shall be capable of retaining the DC balance within ± 0.5 minor divisions over the attenuator range without external operator adjustment.

Equipment:

Items	Model
None	

Procedure:

1. Assure that a front panel or operator accessible DC balance control is not provided. Record the compliance (or lack of compliance) of this specification table 10.3.16.

2. Assure that no cables are connected to the vertical input connectors of the storage oscilloscope.

3. Carefully adjust the sweep of the storage oscilloscope to be coincident with the center horizontal line marked on the graticule.

4. Rotate the vertical attenuator control over the entire range, from 5 mV/div through 5 V/div. Carefully observe the position of the sweep of the display relative to the center horizontal line on the graticule. The position on each of the sweep line should not change by more than 0.5 minor division on all ranges. Record the compliance (or lack of compliance) of this specification in table 10.3.16 for each range.

Table 10.3.16 Direct Current Balance

Measurement Description	Measurement Data	Estimated Measurement Uncertainty	Specification Limits Min.	Max.	Units
DC balance not provided?	____________	N/A	Yes		
5 mV Range Trace movement	____________	0.25		0.5	Minor div
10 mV Range Trace movement	____________	0.25		0.5	Minor div
20 mV Range Trace movement	____________	0.25		0.5	Minor div
50 mV Range Trace movement	____________	0.25		0.5	Minor div
100 mV Range Trace movement	____________	0.25		0.5	Minor div
0.20 V Range Trace movement	____________	0.25		0.5	Minor div
0.50 V Range Trace movement	____________	0.25		0.5	Minor div
1 V Range Trace movement	____________	0.25		0.5	Minor div
2 V Range Trace movement	____________	0.25		0.5	Minor div
5 V Range Trace movement	____________	0.25		0.5	Minor div

10.3 Vertical Section

10.3.17 Vertical Channel Uncalibrated Vernier Indicator

Specification:

An indicator lamp or readout shall be provided for each vertical channel to indicate when the vertical channel uncalibrated vernier control is not in the calibrated position. This is not required for digital oscilloscopes.

Equipment:

Items	Model

None

Procedure:

1. Determine if the storage oscilloscope is a digital oscilloscope as defined in the Notes, Item 9. If the oscilloscope is a digital oscilloscope, do not perform this test.

2. Assure that there is an indicator lamp or readout provided for each vertical channel to indicate when the vertical channel uncalibrated vernier control is not in the calibrated position. Record the compliance (or lack of compliance) of this specification table 10.3.17.

Table 10.3.17 Vertical Channel Uncalibrated Vernier Indicator

Measurement Description	Measurement Data	Estimated Measurement Uncertainty	Specification Limits Min.	Specification Limits Max.	Units
Readout for uncalibrated vert. channel?	______________	N/A	Yes		

10.3 Vertical Section

10.3.18 Vertical Channel Input Connector

Specification:

Each vertical channel shall be provided with a front panel female BNC input connector.

Equipment:

Items	Model
None	

Procedure:

1. Assure that there are female BNC connectors for each vertical channel to indicate when the vertical channel uncalibrated vernier control is not in the calibrated position. Record the compliance (or lack of compliance) of this specification in table 10.3.18.

Table 10.3.18 Vertical Channel Input Connector

Measurement Description	Measurement Data	Estimated Measurement Uncertainty	Specification Limits Min.	Specification Limits Max.	Units
BNC connectors for each vert. channel?	____________	N/A	Yes		

10.3 Vertical Section

10.3.19 Bandwidth Limiting

Specification:

A control shall be provided to limit the vertical response at the -3 dB point of both channels to 20 ± 5 MHz. This capability shall eliminate high frequency interference without affecting normal low frequency performance of the equipment. Frequency response shall roll-off smoothly at a minimum of 6 dB per octave.

Equipment:

Items	Model
Sine-Wave Generator	Tektronix SG 503 or equivalent
BNC Male to BNC Male Coaxial Cable 36 inches (91.4 cm)	Tektronix P/N 012-0482-00 or equivalent

Procedure:

1. Assure that a control is provided to limit the vertical response of the storage oscilloscope. Record the compliance (or lack of compliance) of this specification in table 10.3.19.

2. Connect the equipment as shown below.

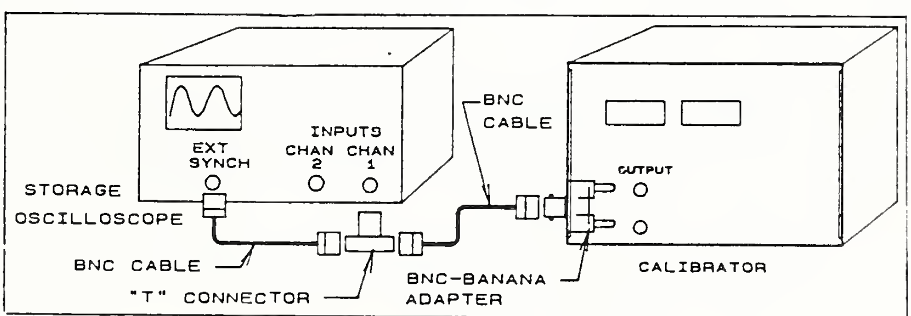


Figure 10.3.19 Test setup for measurement of bandwidth limiting

3. Change the following controls from the default values to that shown below.

Vertical Controls	
VOLTS/DIV	0.5 V
IMPEDANCE	50 Ω
Sweep Controls	
TIME/DIVISION	20 μs
Triggering Controls	
SOURCE	External
TRIGGER MODE	Normal

4. Adjust the output voltage of the sine-wave generator to provide a nominal 3 V peak-to-peak signal at a frequency of 50 kHz.

5. Measure the amplitude of the 50 kHz signal displayed on the storage oscilloscope. Record this value in table 10.3.19 as Vr, denoting the amplitude of the reference voltage level as measured by the oscilloscope.

6. Increase the frequency of the sine-wave generator to 15 MHz. Set sweep to 20 ns.

7. Change the following controls to that shown below.

Vertical Controls	
BANDWIDTH	20 MHz

8. Measure the amplitude of the 15 MHz signal displayed on the storage oscilloscope with the bandwidth-limiting filter on. Record this value in table 10.3.19 as Vl, denoting the amplitude of the 15 MHz signal level as measured by the oscilloscope at the lowest permissible -3 dB response point.

9. Slowly increase the frequency of the sine-wave generator until the amplitude of the of the signal displayed on the storage oscilloscope decreases to 2.124 V peak-to-peak. Record this frequency in table 10.3.19 as f_{-3db}, the frequency at which the response drops to -3 dB below the reference amplitude.

10. Multiply the frequency found in step 9 by a factor of three. Record the result in table 10.3.19 as f_{-10db}.

11. Set the frequency of the sine-wave generator to f_{-10db}.

12. Change the following controls from the default values to that shown below.

Vertical Controls	
VOLTS/DIV	50 mV

13. Measure the amplitude of the peak-to-peak voltage displayed by the storage oscilloscope. It may be necessary to change the input range of the storage oscilloscope to a more sensitive range in order to obtain a display of the signal. Record the amplitude of the voltage in table 10.3.19 as Vf.

14. Calculate the difference in dB of the vertical response of the bandwidth-limiting filter according to the following formula

$$Rf = 20 \log_{10} \frac{V_f}{V_r}$$

Record the value of the response of the filter in table 10.3.19.

Table 10.3.19 Bandwidth Limiting

Measurement Description	Measurement Data	Estimated Measurement Uncertainty	Specification Limits Min.	Max.	Units
Control for 20 MHz filter	________	N/A	Yes		
Reference at 50 kHz, Vr	________	N/A, Ratio Measurement			V p-p
Amplitude at 15 MHz, V1	________	±0.015	2.124		V p-p
Max freq. of -3db, f_{-3db}	________	±0.07		25	MHz
3× the f_{-3db} freq., f_{-10dB}	________	±0.21			MHz
Amplitude at f_{-10dB}, Vf	________	± 1.5			mV p-p
Response at f_{-10dB}, R_f	________	±0.28	-10		dB

2. Connect the equipment as shown below.

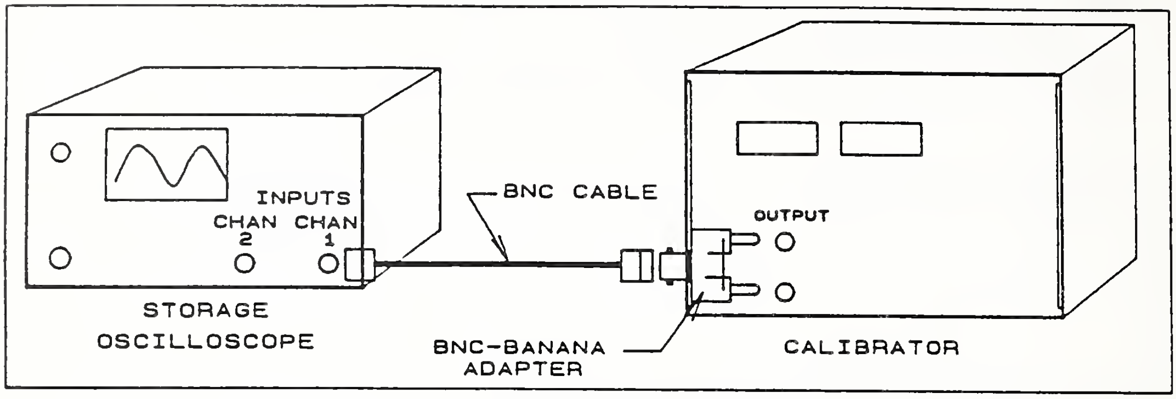


Figure 10.4.1a Test setup for demonstration of sweep trigger mode (normal internal trigger)

3. Adjust the meter calibrator to supply an ac voltage of 2.0 V rms at 1 kHz.

4. Set the storage oscilloscope to trigger from an internal vertical amplifier signal.

5. Assure that the storage oscilloscope triggers, as evidenced by the appearance of a stable display of ten sine waves. Record the compliance (or lack of compliance) of this specification in table 10.4.1. (If the storage oscilloscope fails to trigger, assure that the TRIGGER LEVEL is set to 0.0 volts and that the TRIGGER SLOPE is Positive (+).)

6. Disconnect the cable from the vertical input of the storage oscilloscope.

7. Assure that the storage oscilloscope does not trigger and provide a bright baseline. Record the compliance (or lack of compliance) of this specification in table 10.4.1.

8. Connect the equipment as shown below.

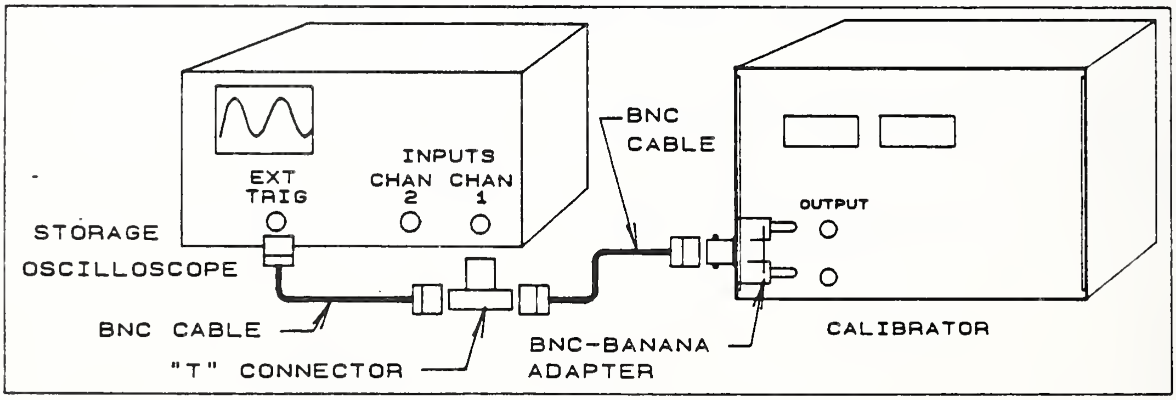


Figure 10.4.1b Test setup for demonstration of sweep trigger mode (normal external trigger)

9. Set the storage oscilloscope to trigger from an external signal.

10. Assure that the storage oscilloscope triggers, as evidenced by the appearance of a stable display of ten sine waves. Record the compliance (or lack of compliance) of this specification in table 10.4.1.

11. Disconnect the cable from the external trigger connector on the storage oscilloscope.

12. Assure that the storage oscilloscope does not trigger. The display may be a vertical line on the left-hand side of the CRT depending on the relative intensity of the display and the blanking operation of the oscilloscope. This condition is considered normal and does not constitute a bright baseline or triggering.[1] Record the compliance (or lack of compliance) of this specification in table 10.4.1.

13. Change the following controls to that shown below.

Sweep Controls	
TIME/DIVISION	10 ms

14. Connect the equipment as shown below.

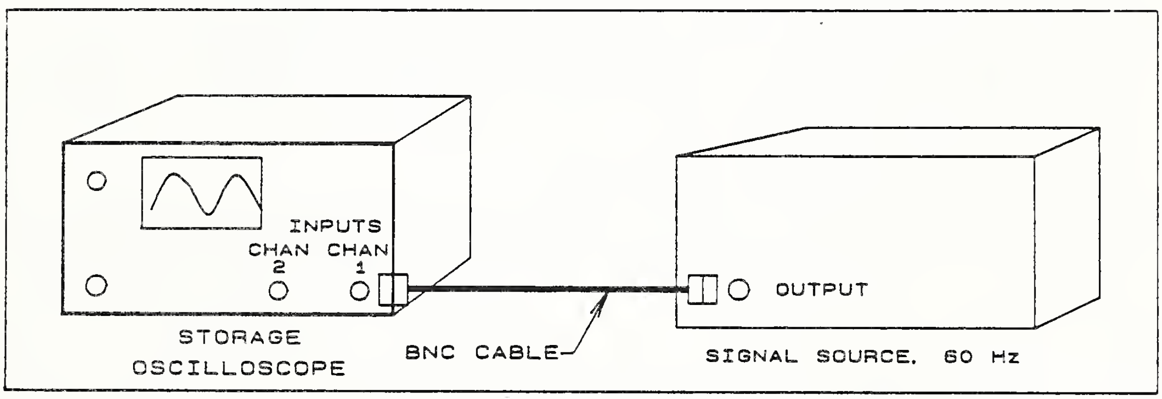


Figure 10.4.1c Test setup for demonstration of sweep trigger mode (normal power line trigger)

15. Connect the signal source to the power line and turn it on.

16. Set the storage oscilloscope to trigger from an internal power line signal.

17. Assure that the storage oscilloscope triggers, as evidenced by the appearance of a stable display of approximately six sine waves. Record the compliance (or lack of compliance) of this specification in table 10.4.1.

18. Disconnect the cable from the vertical input of the storage oscilloscope.

19. Assure that the storage oscilloscope triggers and provides a bright baseline. Record the compliance (or lack of compliance) of this specification in table 10.4.1.

Part 2. Sweep Trigger Mode - Automatic

20. Change the following controls to that shown below.

Sweep Controls	
TIME/DIVISION	1 ms
Triggering Controls	
TRIGGER MODE	Automatic

21. Disconnect all cables from the storage oscilloscope.

22. Assure that the storage oscilloscope triggers and provide a bright baseline. Record the compliance (or lack of compliance) of this specification in table 10.4.1.

23. Change the following controls to that shown below.

Sweep Controls	
TIME/DIVISION	5 ns

24. Assure that the storage oscilloscope triggers and provide a bright baseline. The baseline may not be as bright as displayed when the storage oscilloscope was set to a slower sweep speed, however. This condition is considered normal and constitutes a baseline for faster sweep rates. Record the compliance (or lack of compliance) of this specification in table 10.4.1.

25. Connect the equipment as shown below.

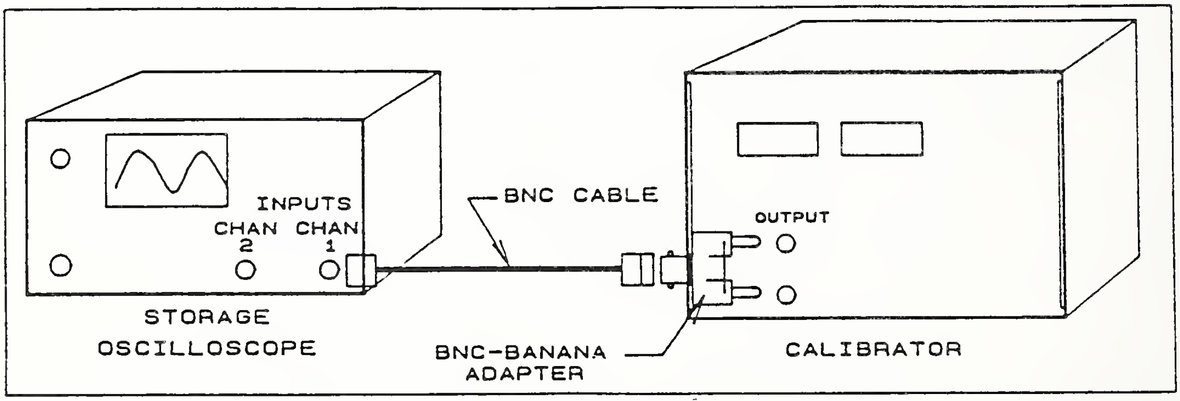


Figure 10.4.1d Test setup for demonstration of sweep trigger mode (automatic)

26. Adjust the meter calibrator to supply an ac voltage of 2.0 V rms at 1 kHz.

27. Change the following controls to that shown below.

Sweep Controls	
TIME/DIVISION	1 ms

28. Assure that the storage oscilloscope continues to trigger, as evidenced by the appearance of a stable display of ten sine waves. Record the compliance (or lack of compliance) of this specification in table 10.4.1.

29. Change the following controls to that shown below.

Sweep Controls
TIME/DIVISION 0.5 s

30. Observe the display for several sweeps and assure that the storage oscilloscope continues to trigger, as evidenced by the appearance of a stable display of a continuous train of sine waves. Record the compliance (or lack of compliance) of this specification in table 10.4.1.

Part 3. Sweep Trigger Mode - Single

31. Change the following controls from the default values to that shown below.

Triggering Controls (both time bases)
TRIGGER MODE Single

Sweep Controls
TIME/DIVISION 1 ms

32. Disconnect all cables from the storage oscilloscope.

33. Assure that the storage oscilloscope does not trigger or provide a bright baseline. Record the compliance (or lack of compliance) of this specification in table 10.4.1.

34. Connect the equipment as shown below.

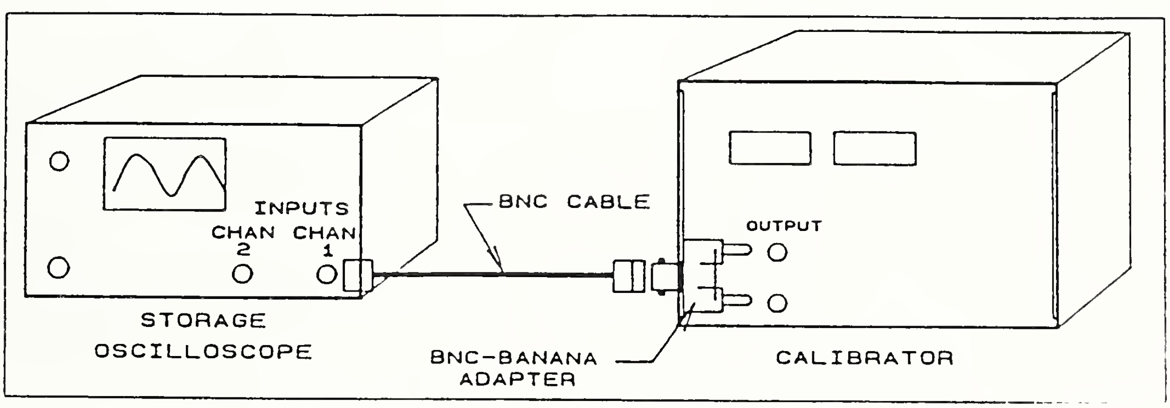


Figure 10.4.1e Test setup for demostration of sweep trigger mode (single)

35. Adjust the meter calibrator to supply an ac voltage of 2.0 V rms at 1 kHz.

36. Disconnect the cable from the vertical input connector of the storage oscilloscope.

37. Arm the oscilloscope for a single sweep. Assure that an indicator is provided to indicate that the sweep is armed. Record the compliance (or lack of compliance) of this specification in table 10.4.1.

38. Connect the cable from the meter calibrator to the vertical input connector of the storage oscilloscope.

39. Assure that the storage oscilloscope triggers once, as evidenced by the appearance of a display of ten sine waves for the duration of the sweep. Record the compliance (or lack of compliance) of this specification in table 10.4.1.

Table 10.4.1 Sweep Trigger Mode

Measurement Description	Measurement Data	Estimated Measurement Uncertainty	Specification Limits Min.	Max.	Units
Normal Mode: Triggers?	____________	N/A	Yes		
Does not trigger?	____________	N/A	Yes		
Triggers?	____________	N/A	Yes		
Does not trigger?	____________	N/A	Yes		
Triggers?	____________	N/A	Yes		
Triggers?	____________	N/A	Yes		
Auto. Mode Triggers?	____________	N/A	Yes		
Triggers?	____________	N/A	Yes		
Triggers?	____________	N/A	Yes		
Triggers?	____________	N/A	Yes		
Single Mode No trigger?	____________	N/A	Yes		
Arming indicator?	____________	N/A	Yes		
Triggers once?	____________	N/A	Yes		

10.4 Horizontal Section

10.4.2 Trigger Level and Slope

Specification:

Controls shall be provided to permit triggering as specified below.

a. *Internal. The internal trigger level and slope shall permit triggering at any point within the trigger sensitivity level (section 10.4.4) on the positive or negative slope of a full screen displayed waveform.*

b. *External. The external level and slope permit continuously variable triggering from at least +0.5 volt to -0.5 volt on either slope of the trigger signal.*

Equipment:

Items	Model
Sine-Wave Generator	Tektronix SG 503 or equivalent
Meter Calibrator	Fluke Model 5101B or equivalent
BNC Male to BNC Male Coaxial Cable 36 inches (91.4 cm)	Tektronix P/N 012-0482-00 or equivalent
BNC Female to Banana Adapter	Pomona 1452 or equivalent
BNC "T" Adapter - Female, Male, Female	Pomona 3285 or equivalent
BNC Male to BNC Male Coaxial Cable 18 inches (45.7 cm)	Pomona BNC-B-18 or equivalent

Procedure:

Part 1. Trigger Level and Slope - Internal

1. Connect the equipment as shown below.

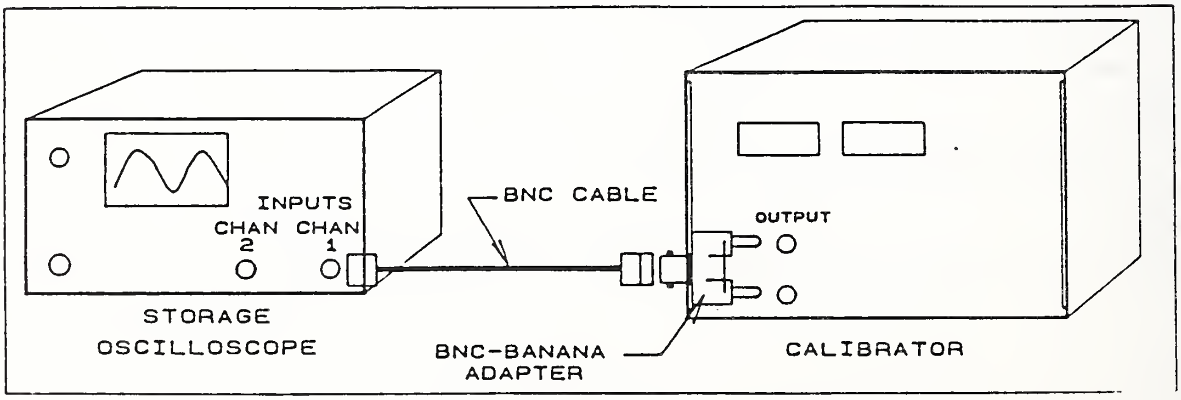


Figure 10.4.2a Test setup for demonstration of trigger level and slope (internal - dc)

2. Set the controls of the storage oscilloscope to the default values given in NOTES, Item 4, p.1. Change the following controls from the default values to that shown below.

Vertical Controls	
VOLTS/DIV	0.5 V
Triggering Controls	
TRIGGER MODE	Normal
SOURCE	Vertical Channel 1

3. Set the output of the meter calibrator to +0.25 V dc (0.5 division).

4. Slowly change the trigger level control around the 0.0 V point. The sweep should reliably trigger, while the trigger control is increased in value, at an amplitude of 0.5 division above the centerline of the display. Record the compliance (or lack of compliance) of this specification in table 10.4.2.

5. Set the output of the meter calibrator to -0.25 V dc (-0.5 division).

6. Slowly change the trigger level control around the 0.0 V point. The sweep should reliably trigger, while the trigger control is decreased in value, at an amplitude of 0.5 division below the centerline of the display. Record the compliance (or lack of compliance) of this specification table 10.4.2.

7. Change the following controls from the default values to that shown below.

Vertical Controls (both channels)	
VOLTS/DIV	0.5 V
IMPEDANCE	50 Ω
Triggering Controls	
TRIGGER MODE	Normal
Sweep Controls	
TIME/DIVISION	10 ns

8. Connect the equipment as shown below.

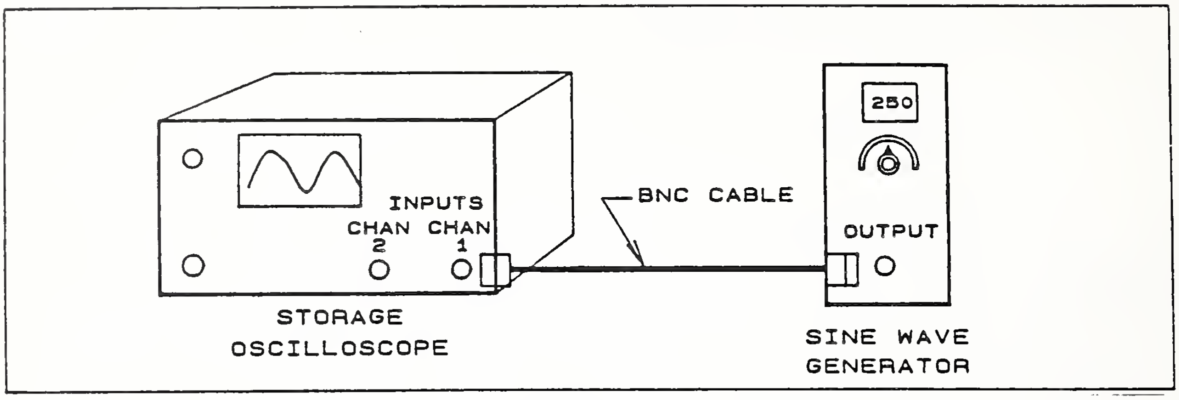


Figure 10.4.2b Test setup for demonstration of trigger level and slope (internal - 50 and 100 MHz)

9. Set the sine-wave generator to provide an output of 4 V p-p at a frequency of 50 MHz. A series of sine waves should fill the screen.

10. Slowly change the trigger level control around the 0.0 V point. The displayed sine wave should reliably trigger, with a positive slope, at any point to within at least 0.5 division of the centerline of the display. Record the compliance (or lack of compliance) of this specification in table 10.4.2.

11. Change the following controls to that shown below

Triggering Controls	
SLOPE	Negative (-)

12. Slowly change the trigger level control around the 0.0 V point. The displayed sine wave should reliably trigger, with a negative slope, at any point to within at least 0.5 division of the centerline of the display. Record the compliance (or lack of compliance) of this specification in table 10.4.2.

13. Change the following controls to that shown below

Triggering Controls	
SLOPE	Positive (+)

14. Set the sine-wave generator to provide an output of 4 V p-p at a frequency of 100 MHz.

15. Slowly change the trigger level control around the 0.0 V point. The displayed sine wave should reliably trigger, with a positive slope, at any point to within at least 1.5 division of the centerline of the display. Record the compliance (or lack of compliance) of this specification in table 10.4.2.

16. Change the following controls to that shown below

Triggering Controls	
SLOPE	Negative (-)

17. Slowly change the trigger level control around the 0.0 V point. The displayed sine wave should reliably trigger, with a negative slope, at any point to within at least 1.5 division of the centerline of the display. Record the compliance (or lack of compliance) of this specification in table 10.4.2.

Part 2. Trigger Level and Slope - External

18. Connect the equipment as shown below.

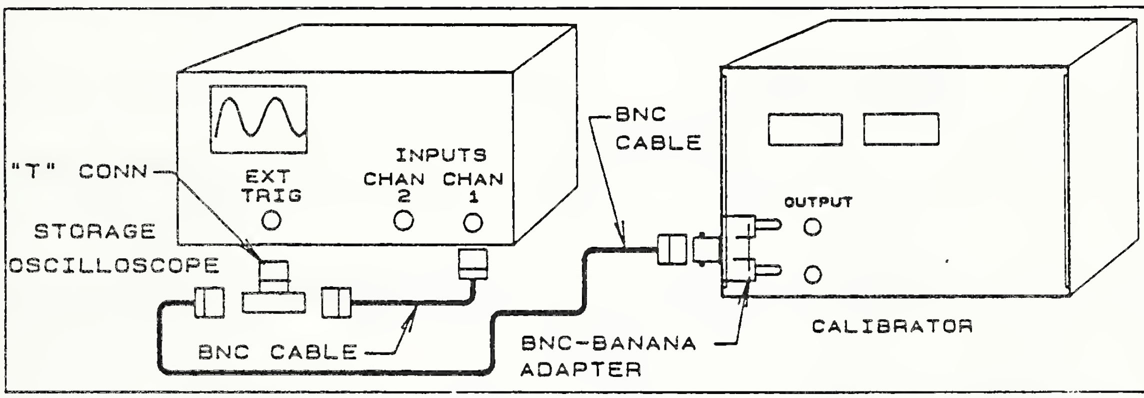


Figure 10.4.2c Test setup for demonstration of trigger level and slope (external - dc)

19. Change the following controls from the default values to that shown below.

Vertical Control	
VOLTS/DIV	0.5 V
IMPEDANCE	1 MΩ
Triggering Controls	
TRIGGER MODE	Normal
SOURCE	External

20. Set the output of the meter calibrator to +0.50 V dc.

21. Slowly change the trigger level control around the 0.0 V point. The sweep should reliably trigger, while the trigger control is increased in value, at an amplitude of 1.0 division above the centerline of the display. Record the compliance (or lack of compliance) of this specification in table 10.4.2.

22. Set the output of the meter calibrator to -0.50 V dc.

23. Slowly change the trigger level control around the 0.0 V point. The sweep should reliably trigger, while the trigger control is decreased in value, at an amplitude of 1.0 division below the centerline of the display. Record the compliance (or lack of compliance) of this specification in table 10.4.2.

24. Change the following controls from the default values to that shown below.

Vertical Controls (both channels)	
VOLTS/DIV	0.5 V
IMPEDANCE	50 Ω
Triggering Controls	
TRIGGER MODE	Normal
Sweep Controls	
TIME/DIVISION	10 ns

25. Connect the equipment as shown below.

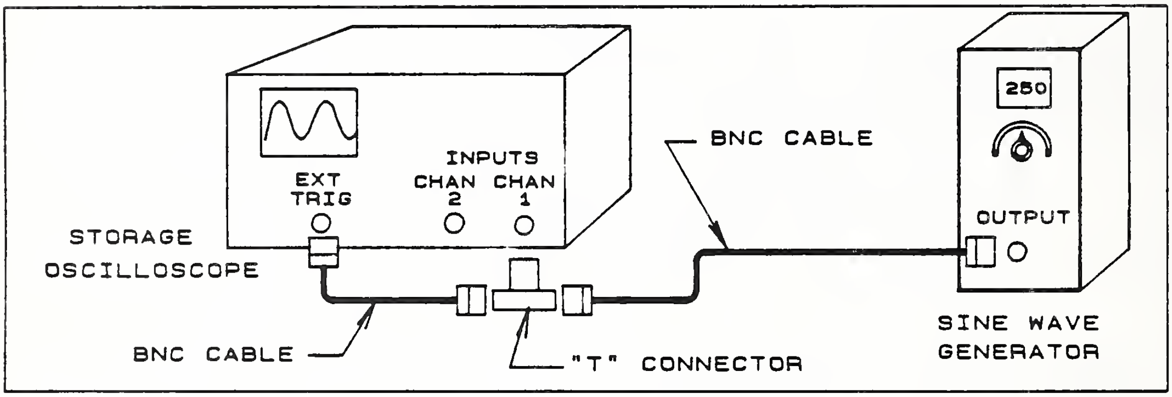


Figure 10.4.2d Test setup for demonstration of trigger level and slope (external - 50 and 100 MHz)

26. Set the sine-wave generator to provide an output of 50 mV p-p at a frequency of 50 MHz.

27. Slowly change the trigger level control around the 0.0 V point. The oscilloscope should reliably trigger. (The displayed sine wave may be too small in amplitude to see, however.) Record the compliance (or lack of compliance) of this specification in table 10.4.2.

28. Set the sine-wave generator to provide an output of 250 mV p-p at a frequency of 100 MHz.

29. Slowly change the trigger level control around the 0.0 V point. The oscilloscope should reliably trigger. (The displayed sine wave may be too small in amplitude to see, however.) Record the compliance (or lack of compliance) of this specification in table 10.4.2.

Table 10.4.2 Trigger Level and Slope

Measurement Description	Measurement Data	Estimated Measurement Uncertainty	Specification Limits Min.	Max.	Units
Internal Trig Trig. on +dc?	____________	N/A	Yes		
Trig. on -dc?	____________	N/A	Yes		
Pos. 50 MHz?	____________	N/A	Yes		
Neg. 50 MHz?	____________	N/A	Yes		
Pos. 100 MHz?	____________	N/A	Yes		
Neg. 100 MHz?	____________	N/A	Yes		
External Trig +0.5 V dc?	____________	N/A	Yes		
-0.5 V dc?	____________	N/A	Yes		
Trig. 50 MHz?	____________	N/A	Yes		
Trig. 100 MHz?	____________	N/A	Yes		

10.4 Horizontal Section

10.4.3 Trigger Source

Specification:

The trigger source shall be selectable from the following:

a. *Channel A [1]. All displays shall be triggered by the Channel A [1] signal.*

b. *Channel B [2]. All displays shall be triggered by the Channel B [2] signal.*

c. *External.*

Equipment:

Items	Model
Sine-Wave Generator	Tektronix SG 503 or equivalent
BNC Male to BNC Male Coaxial Cable 36 inches (91.4 cm)	Tektronix P/N 012-0482-00 or equivalent
BNC "T" Adapter - Female, Male, Female	Pomona 3285 or equivalent
BNC Male to BNC Male Coaxial Cable 18 inches (45.7 cm)	Pomona BNC-B-18 or equivalent

Procedure:

Part 1. Trigger Source - Channel 1:

1. Connect the equipment as shown below.

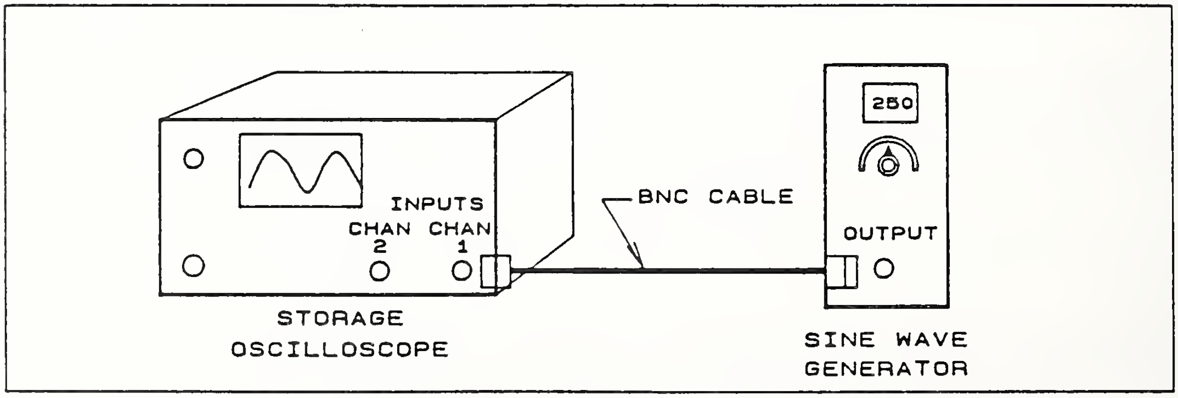


Figure 10.4.3a Test setup for demonstration of trigger source (channel 1)

2. Set the controls of the storage oscilloscope to the default values given in NOTES, Item 4, p.1. Change the following controls from the default values to that shown below.

Vertical Controls	
VOLTS/DIV	0.5 V
IMPEDANCE	50 Ω
Sweep Controls	
TIME/DIVISION	10 μs
Triggering Controls	
TRIGGER MODE	Normal
SOURCE	Vertical Channel 1

3. Set the output of the sine-wave generator to 2 V peak-to-peak (4 divisions) at a frequency of 50 kHz.

4. Set the trigger level control around the 0.0 V point and assure that the A vertical channel reliably triggers. Record the compliance (or lack of compliance) of this specification in table 10.4.3.

5. Set the storage oscilloscope such that vertical Channel 1 triggers vertical Channel 2.

6. Set the storage oscilloscope to display vertical Channel 2.

7. Assure that vertical Channel 2 reliably triggers. Record the compliance (or lack of compliance) of this specification in table 10.4.3.

Part 2. Trigger Source - Channel 2

8. Connect the equipment as shown below.

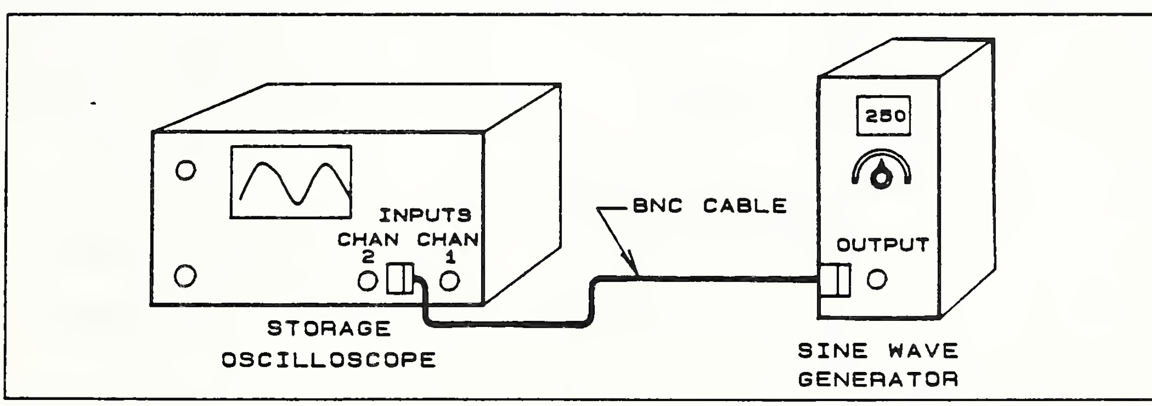


Figure 10.4.3b Test setup for demonstration of trigger source (channel 2)

9. Change the following controls from the default values to that shown below.

Triggering Controls	
TRIGGER MODE	Normal
SOURCE	Vertical Channel 2

10. Set the storage oscilloscope such that vertical Channel 2 triggers vertical Channel 1.

11. Set the storage oscilloscope to display vertical Channel 1.

12. Assure that vertical Channel 1 reliably triggers. Record the compliance (or lack of compliance) of this specification in table 10.4.3.

13. Set the storage oscilloscope such that the B vertical channel triggers vertical Channel 2.

14. Set the storage oscilloscope to display vertical Channel 2.

15. Assure that vertical Channel 2 reliably triggers. Record the compliance (or lack of compliance) of this specification in table 10.4.3.

Part 2. Trigger Level and Slope - External

16. Connect the equipment as shown below.

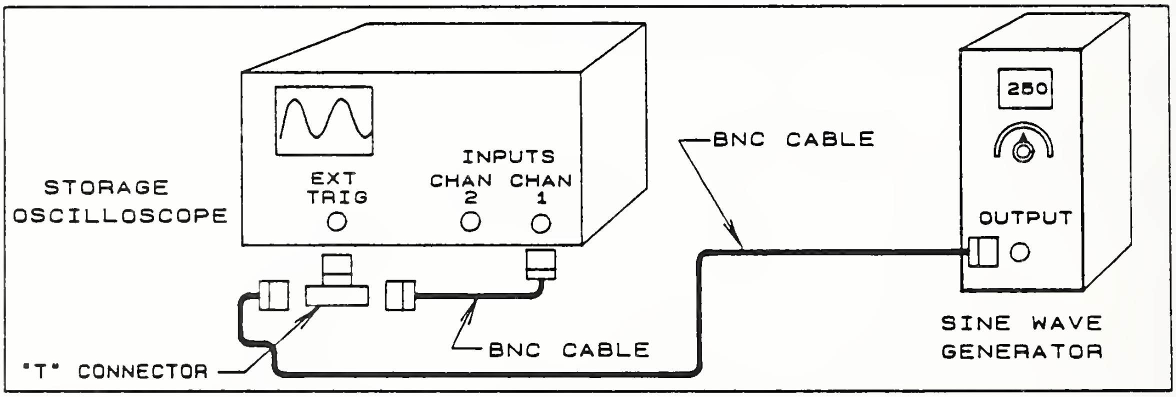


Figure 10.4.3c Test setup for demonstration of trigger source (external)

17. Change the following controls from the default values to that shown below.

Triggering Controls	
SOURCE	External

18. Set the storage oscilloscope such that the external input triggers the vertical Channel 1.

19. Set the storage oscilloscope to display vertical Channel 1.

20. Assure that vertical Channel 1 reliably triggers. Record the compliance (or lack of compliance) of this specification in table 10.4.3.

21. Set the storage oscilloscope such that the external input triggers vertical Channel 2.

22. Set the storage oscilloscope to display vertical Channel 2.

23. Assure that vertical Channel 2 reliably triggers. Record the compliance (or lack of compliance) of this specification in table 10.4.3.

Table 10.4.3 Trigger Source

Measurement Description	Measurement Data	Estimated Measurement Uncertainty	Specification Limits Min.	Max.	Units
1 Source Triggers 1?	________	N/A	Yes		
1 Source Triggers 2?	________	N/A	Yes		
2 Source Triggers 1?	________	N/A	Yes		
2 Source Triggers 2?	________	N/A	Yes		
External Triggers 1?	________	N/A	Yes		
External Triggers 2?	________	N/A	Yes		

10.4 Horizontal Section

10.4.4 Trigger Sensitivity

Specification:

a. *Internal. A stable sweep shall be obtained from a sine wave having at least 0.5 divisions p-p vertical deflection from DC to at least 50 MHz, increasing to 1.5 divisions p-p vertical deflection at 100 MHz.*

b. *External. A stable sweep shall be obtained from a sine wave less than or equal to 50 mV p-p vertical deflection from DC to 50 MHz, increasing to less than or equal to 250 mV p-p vertical deflection at 100 MHz.*

Equipment:

Items	Model
Sine-Wave Generator	Tektronix SG 503 or equivalent
Meter Calibrator	Fluke Model 5101B or equivalent
BNC Male to BNC Male Coaxial Cable 36 inches (91.4 cm)	Tektronix P/N 012-0482-00 or equivalent
BNC Female to Banana Adapter	Pomona 1452 or equivalent
BNC "T" Adapter - Female, Male, Female	Pomona 3285 or equivalent
BNC Male to BNC Male Coaxial Cable 18 inches (45.7 cm)	Pomona BNC-B-18 or equivalent

Procedure:

> Note: Passage of section 10.4.2, "Trigger Level and Slope" constitutes passage of this procedure.

If the procedure on "Trigger Level and Slope" was not successfully passed or was waved by the procuring agency, the following procedure is offered for testing the trigger sensitivity.

Part 1. Trigger Sensitivity - Internal

1. Connect the equipment as shown below.

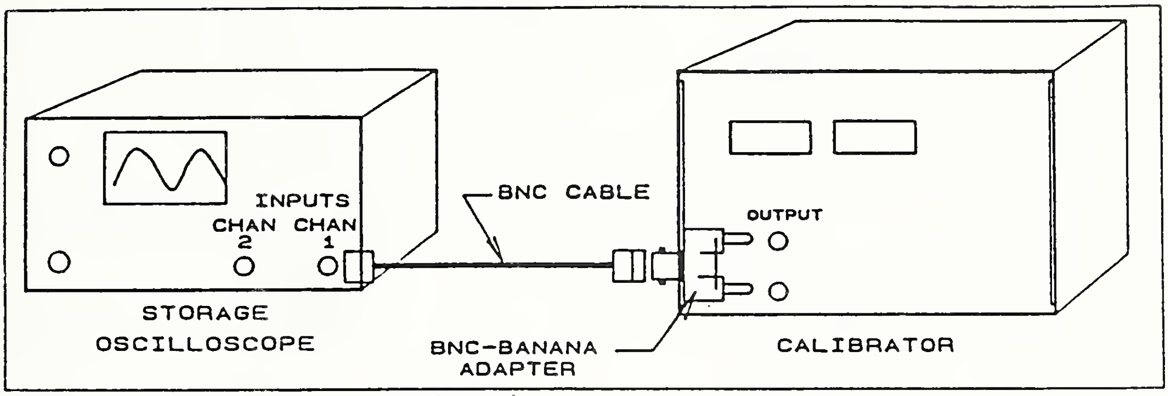


Figure 10.4.4a Test setup for demonstration of trigger sensitivity (internal - dc)

2. Set the controls of the storage oscilloscope to the default values given in NOTES, Item 4, p.1. Change the following controls from the default values to that shown below.

Vertical Controls	
VOLTS/DIV	0.5 V
Triggering Controls	
TRIGGER MODE	Normal
SOURCE	Vertical Channel 1

3. Set the output of the meter calibrator to +0.25 V dc (0.5 division).

4. Slowly change the trigger level control around the 0.0 V point. The sweep should reliably trigger, while the trigger control is decreased in value, at an amplitude of 0.5 division above the centerline of the display. Record the compliance (or lack of compliance) of this specification in table 10.4.4.

5. Set the output of the meter calibrator to -0.25 V dc (-0.5 division).

6. Slowly change the trigger level control around the 0.0 V point. The sweep should reliably trigger, while the trigger control is increased in value, at an amplitude of 0.5 division below the centerline of the display. Record the compliance (or lack of compliance) of this specification in table 10.4.4.

7. Change the following controls from the default values to that shown below.

Vertical Control	
IMPEDANCE	50 Ω
Sweep Controls	
TIME/DIVISION	10 ns

8. Connect the equipment as shown below.

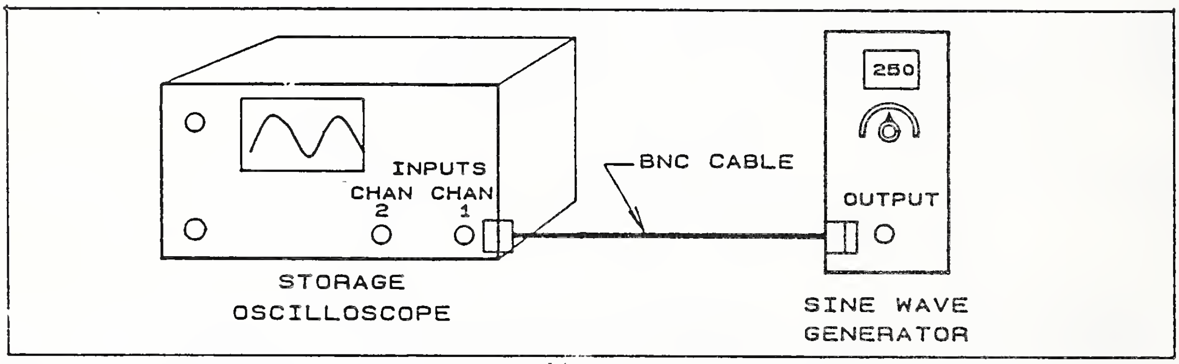


Figure 10.4.4b Test setup for demonstration of trigger sensitivity (internal - 50 and 100 MHz)

9. Set the sine-wave generator to provide an output of 4 V p-p at a frequency of 50 MHz. A series of sine waves should fill the screen.

10. Slowly change the trigger level control around the 0.0 V point. The displayed sine wave should reliably trigger at any point to within at least 0.5 division of the centerline of the display. Record the compliance (or lack of compliance) of this specification in table 10.4.4.

11. Set the sine-wave generator to provide an output of 4 V p-p at a frequency of 100 MHz.

12. Slowly change the trigger level control around the 0.0 V point. The displayed sine wave should reliably trigger at any point to within at least 1.5 division of the centerline of the display. Record the compliance (or lack of compliance) of this specification in table 10.4.4.

Part 2. Trigger Sensitivity - External

13. Connect the equipment as shown below.

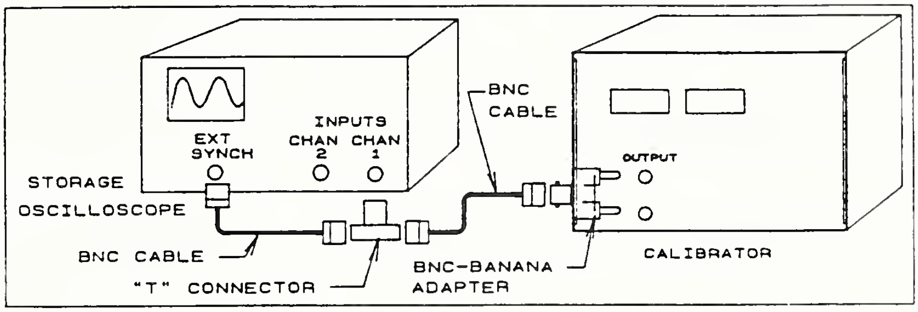


Figure 10.4.4c Test setup for demonstration of trigger sensitivity (external - dc)

14. Change the following controls from the default values to that shown below.

Vertical Control	
VOLTS/DIV	50 mV
IMPEDANCE	1 MΩ
Triggering Controls	
TRIGGER MODE	Normal
SOURCE	External

15. Set the output of the meter calibrator to +50 mV dc.

16. Slowly change the trigger level control around the 0.0 V point. The sweep should reliably trigger, while the trigger control is increased in value, at an amplitude of 1.0 division above the centerline of the display. Record the compliance (or lack of compliance) of this specification in table 10.4.4.

17. Set the output of the meter calibrator to -50 mV dc.

18. Slowly change the trigger level control around the 0.0 V point. The sweep should reliably trigger, while the trigger control is decreased in value, at an amplitude of 1.0 division below the centerline of the display. Record the compliance (or lack of compliance) of this specification in table 10.4.4.

19. Change the following controls from the default values to that shown below.

Vertical Controls	
IMPEDANCE	50 Ω
Triggering Controls	
TRIGGER MODE	Normal
TRIGGER SOURCE	External
Sweep Controls	
TIME/DIVISION	10 ns

20. Connect the equipment as shown below.

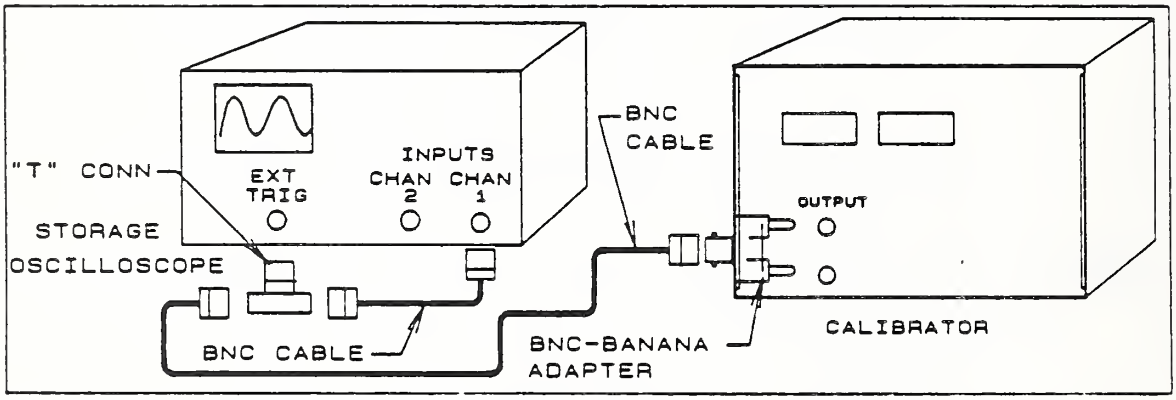


Figure 10.4.4d Test setup for demonstration of trigger sensitivity (external - 50 and 100 MHz)

21. Set the sine-wave generator to provide an output of 50 mV p-p at a frequency of 50 MHz.

22. Change the following controls from the default values to that shown below.

Vertical Control	
VOLTS/DIV	10 mV

23. Assure that the CRT displays a series of sine waves representing a 50 mV 50 MHz signal.

24. Change the following controls from the default values to that shown below.

Vertical Control	
VOLTS/DIV	0.5 V

25. Slowly change the trigger level control around the 0.0 V point. The oscilloscope should reliably trigger. (The displayed sine wave may be too small in amplitude to see, however.) Record the compliance (or lack of compliance) of this specification in table 10.4.4.

26. Set the sine-wave generator to provide an output of 250 mV p-p at a frequency of 100 MHz.

27. Change the following controls from the default values to that shown below.

Vertical Control	
VOLTS/DIV	50 mV

28. Assure that the CRT displays a series of sine waves representing a 250 mV 100 MHz signal.

29. Change the following controls from the default values to that shown below.

Vertical Control	
VOLTS/DIV	0.5 V

30. Slowly change the trigger level control around the 0.0 V point. The oscilloscope should reliably trigger. (The displayed sine wave may be too small in amplitude to see, however.) Record the compliance (or lack of compliance) of this specification in table 10.4.4.

Table 10.4.4 Trigger Sensitivity

Measurement Description	Measurement Data	Estimated Measurement Uncertainty	Specification Limits Min.	Max.	Units
Internal Trig Trig. on +dc?	______	N/A	Yes		
Trig. on -dc?	______	N/A	Yes		
Trig 50 MHz?	______	N/A	Yes		
Trig 100 MHz	______	N/A	Yes		
External Trig Trig. on +dc?	______	N/A	Yes		
Trig. on -dc?	______	N/A	Yes		
Trig 50 MHz?	______	N/A	Yes		
Trig 100 MHz?	______	N/A	Yes		

10.4 Horizontal Section

10.4.5 External Trigger Input

Specification:

a. *Input impedance. The external trigger input impedance shall be 1 megohm ±15 percent paralleled by not more than 22 pf.*

b. *Maximum input. The external trigger input shall withstand, without damage, at least ±100 volts (DC + peak AC).*

c. *Coupling. DC coupling capability shall be provided.*

Equipment:

Items	Model
LF Impedance Analyzer	HP 4192A or equivalent
Meter Calibrator	Fluke 5101B or equivalent
Clock	General Electric 2908 or equivalent
BNC female to Banana Plug Adapter	Pomona 1269 or equivalent
BNC Male to BNC Male Coaxial Cable 24 inches (61 cm) ea.	Pomona BNC-C-24 or equivalent
Isolation Transformer	Topaz 91002-22 or equivalent
Three-wire-female to two-wire-male adapter	Carol, Type ME or equivalent

Procedure:

Part 1. Input Impedance

1. Connect the equipment as shown below.

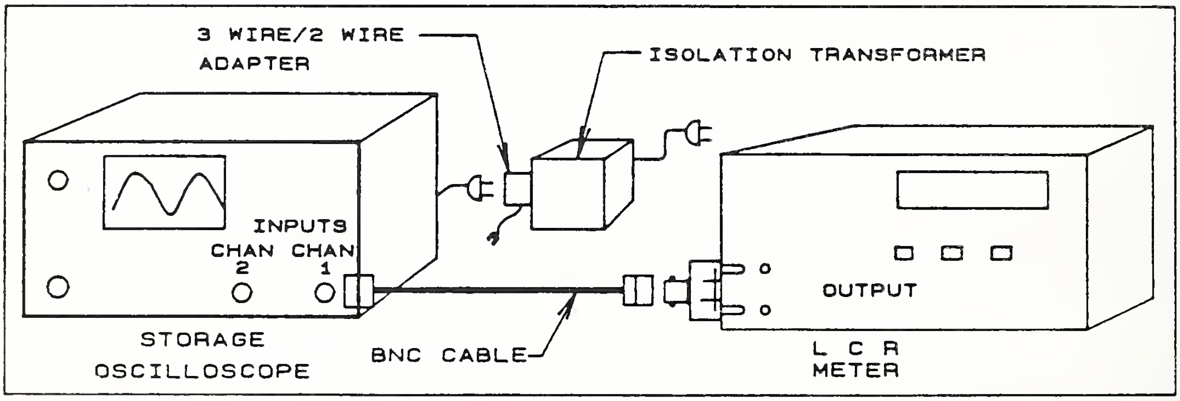


Figure 10.4.5a Test setup for measurement of external trigger input impedance.

Caution: This procedure requires that the chassis of the storage oscilloscope be ungrounded with respect to earth ground. Assure that adequate safety precautions are observed.

2. Set the controls of the storage oscilloscope to the default values given in NOTES, Item 4, p.1. Change the following controls from the default position to that shown below.

Triggering Controls (both time bases)	
SOURCE	External Trigger Input

3. Set the controls on the analyzer as follows.

DC Bias	OFF
Circuit Mode	PRL
Displays	C and R/G
Test Signal	1 kHz
LCR Range	AUTO
ZY Range	AUTO
Trigger	INT
OSC Level	1.0V

4. Disconnect the cable to the input of the time base EXTERNAL TRIGGER connector.

5. Read and record in table 10.4.5 the value of the cable capacitance as indicated by the analyzer.

6. Reconnect the cable to the input of the time base EXTERNAL TRIGGER connector.

7. Read and record in table 10.4.5 the value of the sum of the cable and input capacitance of the time base trigger as indicated by the analyzer.

8. Subtract the value of the capacitance obtained in step 5 from the value of the capacitance obtained in step 7. Record this difference in table 10.4.5 as the input capacitance of the time base trigger.

9. Press the R/ESR button on the analyzer.

10. Read and record in table 10.4.5 the value of the input resistance of the time base trigger as indicated on the analyzer.

Part 2. Maximum Input

> WARNING: This procedure uses lethal voltages during the test. Care should be taken to avoid injury or shock.

11. Connect the equipment as shown below.

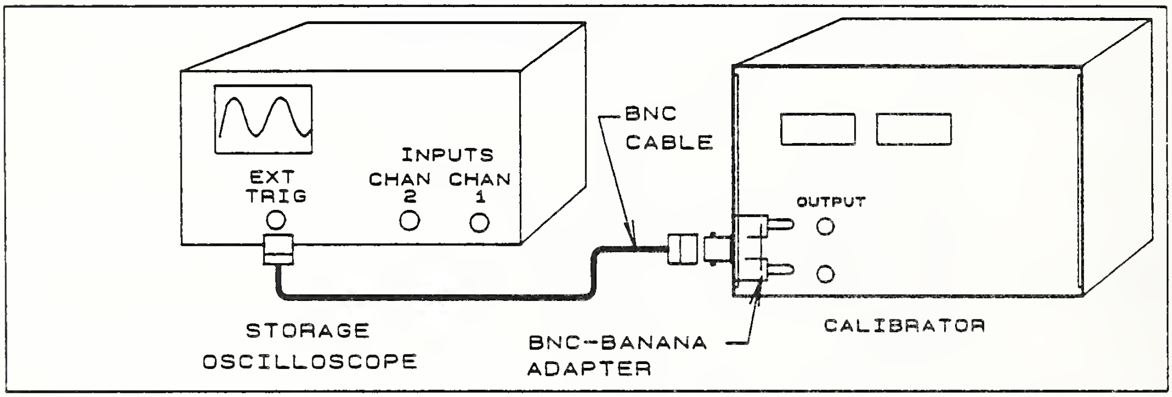


Figure 10.4.5b Test setup for measurement of external trigger, maximum input.

12. Set the controls of the storage oscilloscope to the default values given in NOTES, Item 4, p.1. Change the following controls from the default position to that shown below.

Triggering Controls (both time bases)	
SOURCE	External Trigger Input

13. Apply 100 volts dc from the meter calibrator to the time base EXTERNAL TRIGGER connector. Note time on the clock.

14. After 5 minutes has elapsed, note any evidence of smoking, arcing, or charring of the storage oscilloscope. Note the presence of any evidence of damage in table 10.4.5.

15. Remove the voltage from the storage oscilloscope, and then apply -100 volts dc from the meter calibrator to the time base EXTERNAL TRIGGER connector and repeat step 14, above.

16. Remove the voltage from the storage oscilloscope, and apply 70.7 vac rms, 1 kHz signal to the EXTERNAL TRIGGER connector and repeat step 14, above.

17. Record the results of steps 14 through 16 in table 10.4.5.

Part 3. Coupling

18. Assure that the external trigger inputs have a provision for dc coupling. Record the compliance (or lack of compliance) of this specification in table 10.4.5.

Table 10.4.5 External Trigger Inputs

Measurement Description	Measurement Data	Estimated Measurement Uncertainty	Specification Limits Min.	Max.	Units
Cable Capacitance	____________				pF
Cable + Input Cap.	____________				pF
Trigger Input Cap.	____________	±0.15		22	pF
Trigger Input Res.	____________	±0.003	0.85	1.15	MΩ
Trigger +100 v dc?	____________	N/A	No damage		
Trigger -100 v dc?	____________	N/A	No damage		
Trigger 70.7 v ac?	____________	N/A	No damage		
Trigger dc coupled?	____________	N/A	Yes		

10.4 Horizontal Section

10.4.6 External Trigger Input Connector

Specification:

A front panel female BNC input connector shall be provided.

Equipment:

Items	Model
None	

Procedure:

1. Examine the front panel of the storage oscilloscope. Note the existence of a front panel, female BNC input connector for the time base EXTERNAL TRIGGER.

2. Record the compliance (or lack of compliance) of this specification in table 10.4.6.

Table 10.4.6 External Trigger Input Connectors

Measurement Description	Measurement Data	Estimated Measurement Uncertainty	Specification Limits Min.	Max.	Units
An external input conn.?	________	N/A	Yes		

10.4 Horizontal Section

10.4.7 Trigger Coupling

Specification:

Controls shall be provided for the following type of trigger couplings:

a. *Direct Current (DC). This type of coupling shall be provided for coupling signals from DC to 100 MHz.*

b. *Alternating Current (AC). This type of coupling shall incorporate a high pass filter which attenuates signals less than 30 Hz.*

c. *Low Frequency Rejection. This type of coupling shall incorporate a high pass filter which attenuates signals less than 15 KHz (main time base only).*

d. *High Frequency Rejection. This type of coupling shall incorporate a low pass filter which attenuates signals greater than 50 KHz (main time base only).*

Equipment:

Items	Model
Sine-Wave Generator	Tektronix SG 503 or equivalent
Meter Calibrator	Fluke Model 5101B or equivalent
BNC Male to BNC Male Coaxial Cable 36 inches (91.4 cm)	Tektronix P/N 012-0482-00 or equivalent
BNC Female to Banana Adapter	Pomona 1452 or equivalent

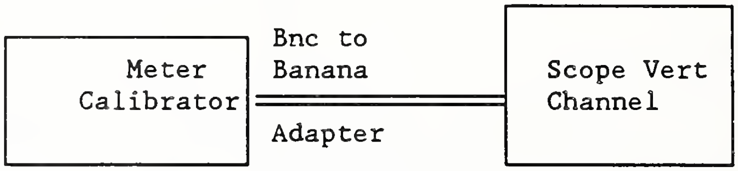
Procedure:

Part 1. Trigger Coupling - Direct Current to 100 MHz

1. Set the controls of the storage oscilloscope to the default values given in NOTES, Item 4, p.1. Change the following controls from the default values to that shown below.

Triggering Controls (both time bases)
TRIGGER MODE Normal

2. Connect the equipment as shown below.



This figure is a placekeeper only. It will be replaced by an appropriate drawing in final version.

Figure 10.4.7a Test setup for demonstration of trigger coupling (dc output of meter calibrator)

3. Adjust the meter calibrator to supply a voltage of -1.0 V dc.

4. Press the ENABLE button on the meter calibrator to intensify the least significant digit on the OUTPUT display. Press the ◁ DECADE button three times to intensify the 0.01 V digit on the OUTPUT display.

5. Rotate the EDIT knob clockwise to cause the output voltage to decrease towards zero volts. Continue to turn the EDIT knob until the output voltage is positive. The storage oscilloscope should trigger, as evidenced by the appearance of a bright baseline, as the trigger point is crossed. Record the compliance (or lack of compliance) of this specification in table 10.4.7a. (If the storage oscilloscope fails to trigger, assure that the TRIGGER LEVEL is set to 0.0 volts and that the TRIGGER SLOPE is Positive (+).)

6. Disconnect the cable from the BNC Female to Banana Adapter at the meter calibrator end.

7. Change the following controls from the default values to that shown below.

Vertical Controls (both channels)	
IMPEDANCE	50 Ω
Sweep Controls	
A TIME/DIVISION	10 ms

The storage oscilloscope should not be triggered.

8. Enable the WIDE BAND output of the meter calibrator. Adjust the meter calibrator to supply a voltage of 1 V ac (rms) at a frequency of 10 Hz.

9. Connect the cable to the wideband output connector as shown in the figure below. The scope should trigger and display a sine wave. Record the compliance (or lack of compliance) of this specification in table 10.4.7a.

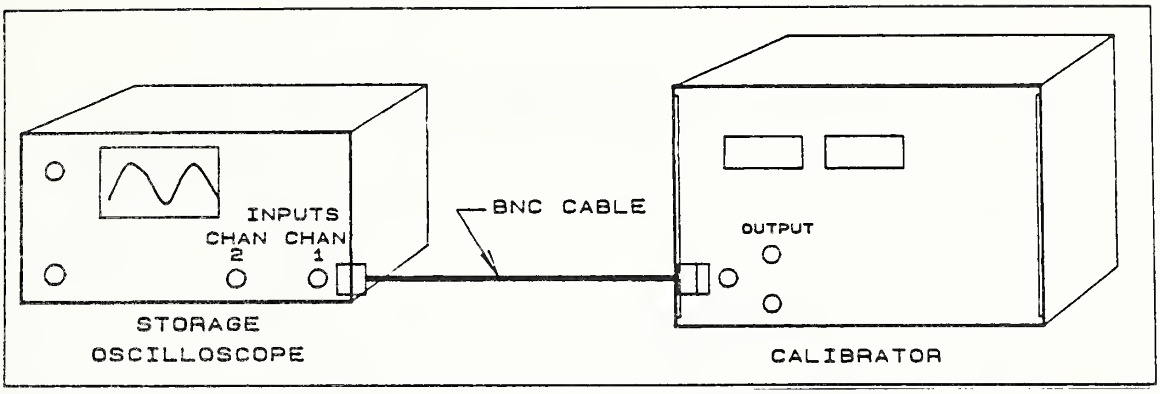


Figure 10.4.7b Test setup for the measurement of trigger coupling (wide band output of meter calibrator)

10. Change the following controls to that shown below.

    Sweep Controls
    A TIME/DIVISION 0.1 ms

11. Increase the frequency to 1 kHz. The scope should trigger and display a sine wave. Record the compliance (or lack of compliance) of this specification in table 10.4.7a.

12. Change the following controls to that shown below.

    Sweep Controls
    A TIME/DIVISION 0.1 µs

13. Increase the frequency to 1 MHz. The scope should trigger and display a sine wave. Record the compliance (or lack of compliance) of this specification in table 10.4.7a.

14. Change the following controls to that shown below.

    Sweep Controls
    A TIME/DIVISION 10 ns

15. Increase the frequency to 10 MHz. The scope should trigger and display a sine wave. Record the compliance (or lack of compliance) of this specification in table 10.4.7a.

16. Disconnect the cable from the the meter calibrator.

17. Connect the cable to the sine-wave generator as shown below.

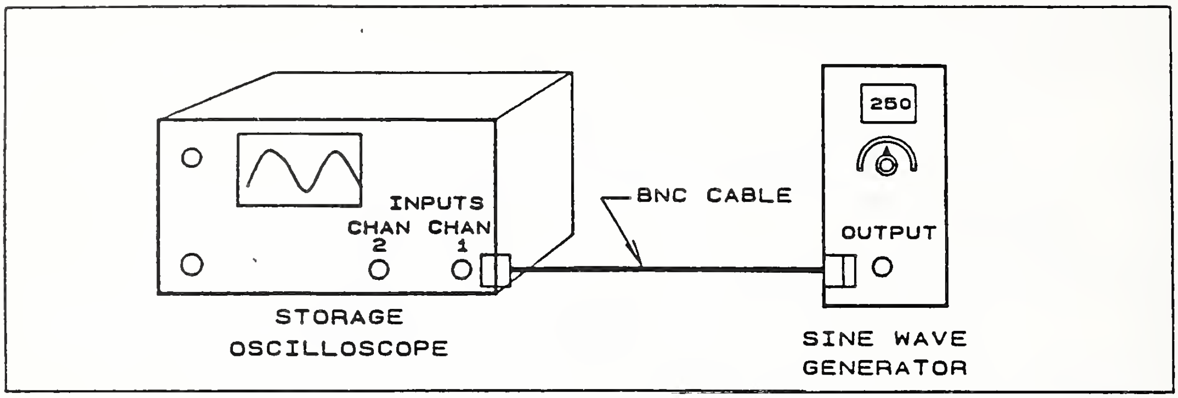


Figure 10.4.7c Test setup for demonstration of trigger coupling (sine-wave generator)

18. Adjust the sine-wave generator for an output of 1 V ac (rms) at a frequency of 100 MHz.

19. The scope should trigger and display ten sine waves. Record the compliance (or lack of compliance) of this specification in table 10.4.7a.

Part 2. Trigger Coupling - Alternating Current

20. Change the following controls from the default values to that shown below.

Vertical Controls (both channels)	
IMPEDANCE	1 MΩ
Triggering Controls (both time bases)	
COUPLING	AC
Sweep Controls	
TIME/DIVISION	10 ms

21. Connect the cable to the dc output of the meter calibrator as shown in figure 10.4.7a. Adjust the meter calibrator to supply a voltage of -1.0 V dc.

22. Press the ENABLE button on the meter calibrator to intensify the least significant digit on the OUTPUT display. Press the ◁ DECADE button three times to intensify the 0.01 V digit on the OUTPUT display.

23. Rotate the EDIT knob clockwise to cause the output voltage to decrease towards zero volts. Continue to turn the EDIT knob until the output voltage is positive. The storage oscilloscope not should trigger as the trigger point (0 V dc) is crossed. Record the compliance (or lack of compliance) of this specification in table 10.4.7a.

24. Disconnect the cable from the BNC Female to Banana Adapter at the meter calibrator end.

24. Disconnect the cable from the BNC Female to Banana Adapter at the meter calibrator end.

25. Change the following controls from the default values to that shown below.

    Vertical Controls (both channels)
    IMPEDANCE 50 Ω

    The storage oscilloscope should not be triggered.

26. Enable the WIDE BAND output of the meter calibrator. Adjust the meter calibrator to supply a voltage of 1 V ac (rms) at a frequency of 10 Hz.

27. Connect the cable to the wideband output connector of the meter calibrator as shown in figure 10.4.7b. The scope should not trigger. Record the compliance (or lack of compliance) of this specification in table 10.4.7a.

28. Change the following controls to that shown below.

    Sweep Controls
    A TIME/DIVISION 0.1 ms

29. Increase the frequency to 1 kHz. The scope should trigger and display a sine wave. Record the compliance (or lack of compliance) of this specification in table 10.4.7b.

Part 3. Trigger Coupling - Low Frequency Rejection

30. Change the following controls to that shown below.

    Sweep Controls
    A TIME/DIVISION 10 ms
    Triggering Controls (both time bases)
    COUPLING Low Frequency Rejection

31. Adjust the meter calibrator to supply a voltage of 1 V ac (rms) at a frequency of 10 Hz.

32. Connect the cable to the wideband output connector. The scope should not trigger. Record the compliance (or lack of compliance) of this specification in table 10.4.7b.

33. Change the following controls to that shown below.

    Sweep Controls
    A TIME/DIVISION 0.1 ms

Table 10.4.7a Trigger Coupling - DC and AC Trigger

Measurement Description	Measurement Data	Estimated Measurement Uncertainty	Specification Limits Min.	Max.	Units
DC Trigger on dc voltage?	____________	N/A	Yes		
DC Trigger at 10 Hz?	____________	N/A	Yes		
DC Trigger at 1 kHz?	____________	N/A	Yes		
DC Trigger at 1 MHz?	____________	N/A	Yes		
DC Trigger at 10 MHz?	____________	N/A	Yes		
DC Trigger at 100 MHz?	____________	N/A	Yes		
AC Trigger on dc voltage?	____________	N/A	No		
AC Trigger at 10 Hz?	____________	N/A	No		
AC Trigger at 1 kHz?	____________	N/A	Yes		

Table 10.4.7b Trigger Coupling - Low Frequency Rejection and High Frequency Rejection

Measurement Description	Measurement Data	Estimated Measurement Uncertainty	Specification Limits Min.	Specification Limits Max.	Units
LF Rej. Trig. at 10 Hz?	____________	N/A	No		
LF Rej. Trig. at 1 kHz?	____________	N/A	No		
LF Rej. Trig. at 20 kHz?	____________	N/A	Yes		
HF Rej. Trig. at 10 Hz?	____________	N/A	Yes		
HF Rej. Trig. at 1 kHz?	____________	N/A	No		
HF Rej. Trig. at 1 MHz?	____________	N/A	No		

10.4 Horizontal Section

10.4.8 Trigger Jitter

Specification:

Trigger jitter shall not exceed 50 psec at 100 MHz.

Equipment:

Items	Model
Sine-Wave Generator	Tektronix SG 503 Leveled Sine or equivalent
Signal Splitter	NIST supplied
Two 36" coaxial cables (Male BNC connectors)	Tektronix P/N 012-0482-00 or equivalent
One 50 Ω BNC termination	Kings 1340-1-M06 or equivalent
Optical comparator (15X)	Bishop No. 3561 or equivalent

Procedure:

1. Connect the output of the generator to the storage oscilloscope using the signal splitter and cables (see figure 10.4.8).

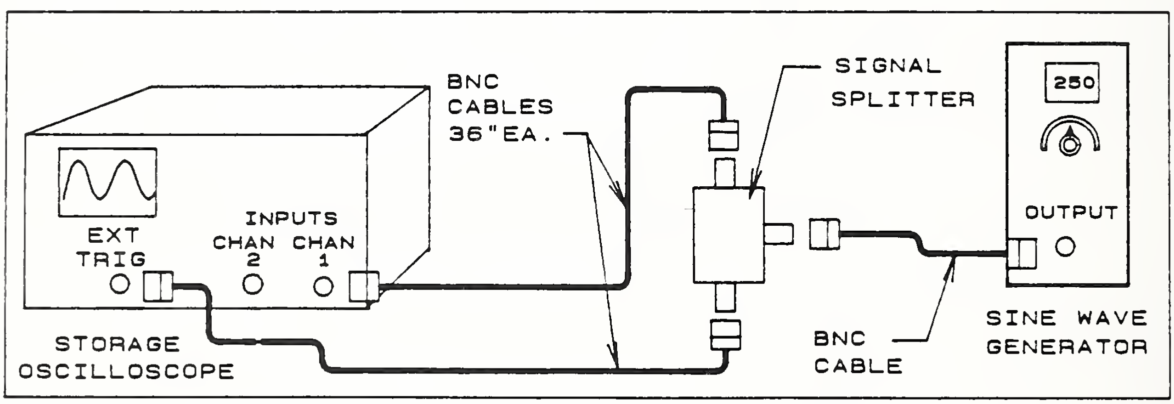


Figure 10.4.8 Test setup for measuring trigger jitter

2. Set the range of the two storage oscilloscope channels to 50 mV/div. and set the coupling to dc 50Ω ON.

3. Set the frequency of the sine-wave generator to 100 MHz and adjust its output amplitude for a peak-to-peak oscilloscope deflection of approximately 6 cm (300 mV).

4. Actuate the external trigger mode on the scope and adjust the trigger controls for the sharpest display of the sine wave, particularly with respect to trigger jitter. Also, use the fastest sweep speed available (10 ns/div or faster).

5. Measure the p-p jitter along the horizontal axis, using the optical comparator. The comparator should be placed on the scope screen and adjusted for a sharp focus, and then used to measure the line width at an axis crossing near the center of the screen. Use the millimeter scale. Record the data in the second column of table 10.4.8.

6. Use the internal trigger mode on the scope, and repeat the measurement described in step 5. Record the smallest p-p jitter obtained, using external or internal trigger, in table 10.4.8.

7. Deactivate the external trigger mode and actuate the internal trigger mode on the storage oscilloscope.

8. Repeat step 5.

9. Convert the measurement data in column 2 to picoseconds using the following formula:

$$\text{Jitter (ps)} = \left[\text{Jitter (mm)}\right]\left[\text{Sweep Speed (ns/div)}\right]\left[100\right]$$

10. Record the results in column 3 of table 10.4.8de.

Table 10.4.8 Measured Trigger Jitter

Measurement Description	Measurement Data	Peak-to-Peak Jitter	Estimated Measurement Uncertainty	Specification Limits Min	Specification Limits Max
Jitter External Trigger	________mm	________ps	± 150 ps		50 ps
Jitter Internal Trigger	________mm	________ps	± 150 ps		50 p s

10.4 Horizontal Section

10.4.9 Trigger Hold-off

Specification:

A trigger hold-off control shall be provided to permit the hold-off period to be continuously variable to at least 10.0 times the time per division of each horizontal range from 20 msec per division through 10 nsec per division. This is not required for digital oscilloscopes.

Equipment:

Items	Model
Pulse Generator, 2 ea.	Tektronix PG 508 or equivalent
BNC Male to BNC Male Coaxial Cable 36 inches (91.4 cm), 3 ea	Tektronix P/N 012-0482-00 or equivalent
BNC "T" Adapter - Female, Male, Female	Pomona 3285 or equivalent

Procedure:

1. Set the controls of the storage oscilloscope to the default values given in NOTES, Item 4, p.1. Change the following controls from the default values to that shown below.

Vertical Controls (both channels)	
VOLTS/DIV	0.5 V
IMPEDANCE	50 Ω
Triggering Controls (both time bases)	
LEVEL	300 mV
SLOPE	Positive (+)
COUPLING	DC
SOURCE	Vertical Channel A
TRIGGER MODE	Normal
Sweep Controls	
HORIZONTAL DISPLAY	A Sweep
A TIME/DIVISION	50 ns/cm
TRIGGER HOLD-OFF	Set for zero hold-off (or as near to zero as possible).

2. Connect the equipment as shown below.

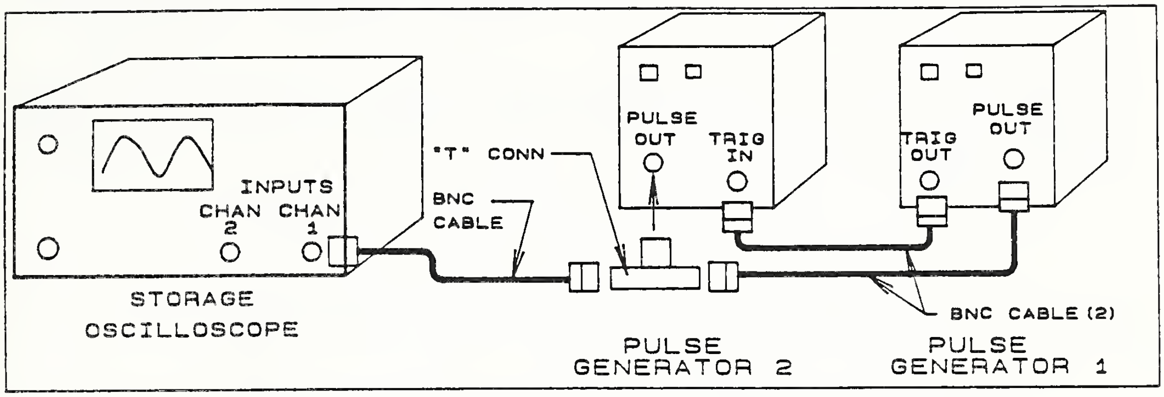


Figure 10.4.9a Test setup for measurement of trigger hold-off

3. Set the two pulse generators as follows:

Pulse Generator #1 - Main Pulse Generator

PERIOD	2 μs range
DELAY	10 ns range
DURATION	10 ns range
TRANSITION TIMES	
LEADING EDGE	approx. 3 ns
TRAILING EDGE	approx. 3 ns
MODE	Undelayed
TRIGGER LEVEL	0.0 V
OUTPUT LEVELS	
HIGH	+1 V
LOW	0 V

Pulse Generator #2 - Delayed Pulse Generator

PERIOD	2 μs range
DELAY	10 ns range
DURATION	10 ns range
TRANSITION TIMES	
LEADING EDGE	approx. 3 ns
TRAILING EDGE	approx. 3 ns
MODE	Delayed
TRIGGER LEVEL	0.0 V
OUTPUT LEVELS	
HIGH	+2 V
LOW	0 V

The intent of this setup is to have the first pulse generator trigger the second pulse generator. The pulse from the first generator is approximately one volt in amplitude, while the pulse from the second generator is approximately 2 volts in amplitude. The time between the first and second pulse may be varied by adjusting the pulse delay control located on the second pulse generator. In this manner, two pulses may be generated that are distinguishable in amplitude and have an adjustable time delay.

4. Adjust the DELAY control of the second pulse generator such that the delay between the first and second pulses is 500 ns.

5. Adjust the trigger level of the storage oscilloscope to a value between 0 V and 1 V such that the oscilloscope triggers on both the first and second pulses. In this condition, the presentation will be as shown in the figure below.

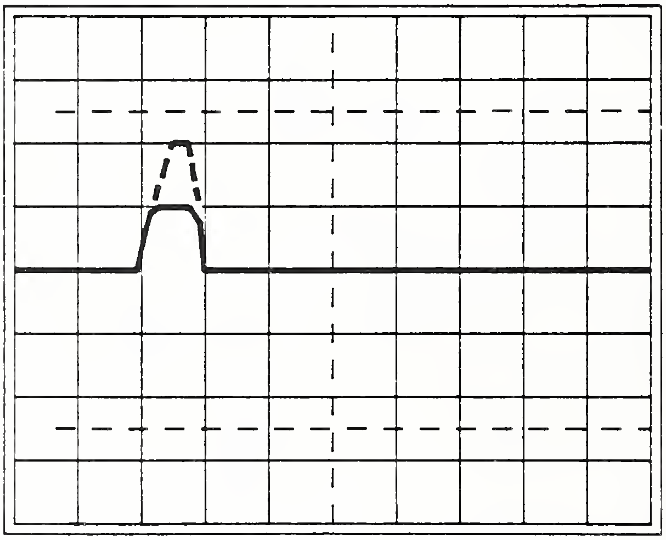


Figure 10.4.9b Display of trigger hold-off (insufficient hold-off)

6. Adjust the trigger hold-off control on the storage oscilloscope to a point such that the oscilloscope triggers on the first, lower amplitude pulse, but does not trigger on the second pulse. Since the second pulse is "off the screen" to the right of the first pulse, it will not be seen.

7. The display, with the trigger hold-off properly adjusted, should look as shown below.

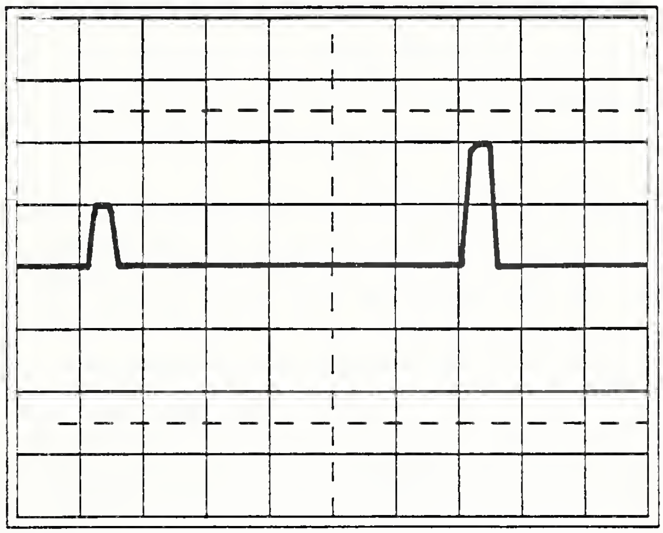


Figure 10.4.9c Display of trigger hold-off (hold-off properly adjusted)

8. Record the compliance (or lack of compliance) of this specification in table 10.4.9.

9. Change the controls on the storage oscilloscope as follows:

Sweep Controls

HORIZONTAL DISPLAY	A Sweep
A TIME/DIVISION	20 ms/cm
TRIGGER HOLD-OFF	Set for zero hold-off (or as near to zero as possible).

Pulse Generator #1 - Main Pulse Generator

PERIOD	2 ms range
DELAY	20 μs range
DURATION	20 μs range
TRANSITION TIMES	
LEADING EDGE	approx. 5 μs
TRAILING EDGE	approx. 5 μs
MODE	Undelayed

Pulse Generator #2 - Delayed Pulse Generator

PERIOD	2 ms range
DELAY	20 μs range
DURATION	20 μs range
TRANSITION TIMES	
LEADING EDGE	approx. 5 μs
TRAILING EDGE	approx. 5 μs
MODE	Delayed

10. Adjust the DELAY control of the second pulse generator such that the delay between the first and second pulses is 200 ms.

11. Adjust the trigger hold-off control on the storage oscilloscope to a point such that the oscilloscope triggers on the first, lower amplitude pulse, but does not trigger on the second pulse. Since the second pulse is "off the screen" to the right of the first pulse, it will not be seen.

12. Adjust the DELAY control of the second pulse generator such that the delay between the first and second pulse is 200 ms.

13. Adjust the trigger hold-off control on the storage oscilloscope to a point such that the oscilloscope triggers on the first, lower amplitude pulse, but does not trigger on the second pulse. Since the second pulse is "off the screen" to the right of the first pulse, it will not be seen.

14. Record the compliance (or lack of compliance) of this specification in table 10.4.9.

Table 10.4.9 Trigger Hold-off

Measurement Description	Measurement Data	Estimated Measurement Uncertainty	Specification Limits Min.	Specification Limits Max.	Units
Trigger hold-off at 500 ns?	____________	N/A	Yes		
Trigger hold-off at 200 ms?	____________	N/A	Yes		

10.4 Horizontal Section

10.4.10 Time Base (Main)

Specification:

The time base shall provide calibrated sweep times in a 5-2-1 sequence from 5 nsec or less/division to 0.5 seconds or more/division. A control shall be provided to select the calibrated sweep times of the main time base.

Equipment:

Items	Model

None

Procedure:

1. Examine the storage oscilloscope to assure that that a main time base is provided with calibrated sweep times in accordance with the values given in tables 10.4.10.

2. Record the compliance (or lack of compliance) of this specification in table 10.4.10.

Table 10.4.10 Time Base (Main)

Measurement Description	Measurement Data	Estimated Measurement Uncertainty	Specification Limits Min.	Max.	Units
0.5 s sweep time exists?	______________	N/A	Yes		
0.2 s sweep time exists?	______________	N/A	Yes		
0.1 s sweep time exists?	______________	N/A	Yes		
50 ms sweep time exists?	______________	N/A	Yes		
20 ms sweep time exists?	______________	N/A	Yes		
10 ms sweep time exists?	______________	N/A	Yes		
5 ms sweep time exists?	______________	N/A	Yes		
2 ms sweep time exists?	______________	N/A	Yes		
1 ms sweep time exists?	______________	N/A	Yes		
500 μs sweep time exists?	______________	N/A	Yes		
200 μs sweep time exists?	______________	N/A	Yes		
100 μs sweep time exists?	______________	N/A	Yes		
50 μs sweep time exists?	______________	N/A	Yes		

Table 10.4.10 Time Base (Main) - con't

Measurement Description	Measurement Data	Estimated Measurement Uncertainty	Specification Limits Min.	Max.	Units
20 μs sweep time exists?	______________	N/A	Yes		
10 μs sweep time exists?	______________	N/A	Yes		
5 μs sweep time exists?	______________	N/A	Yes		
2 μs sweep time exists?	______________	N/A	Yes		
1 μs sweep time exists?	______________	N/A	Yes		
500 ns sweep time exists?	______________	N/A	Yes		
200 ns sweep time exists?	______________	N/A	Yes		
100 ns sweep time exists?	______________	N/A	Yes		
50 ns sweep time exists?	______________	N/A	Yes		
20 ns sweep time exists?	______________	N/A	Yes		
10 ns sweep time exists?	______________	N/A	Yes		
5 ns sweep time exists?	______________	N/A	Yes		
	______________				

10.4 Horizontal Section

10.4.10.1 Time Base Accuracy

Specification:

The calibrated sweep time shall be ±2 percent of the setting.

Equipment:

Items	Model
Time Mark Generator	Tektronix Model TG 501 or equivalent
Two 36" Coaxial Cables with male BNC connectors	Pomona BNC-C-36

Procedure:

1. Connect the time mark generator to the oscilloscope as shown in figure 10.4.10.1 on this measurement and following measurements, either internal or external trigger may be used. (On some waveforms, one may be more effective than the other.)

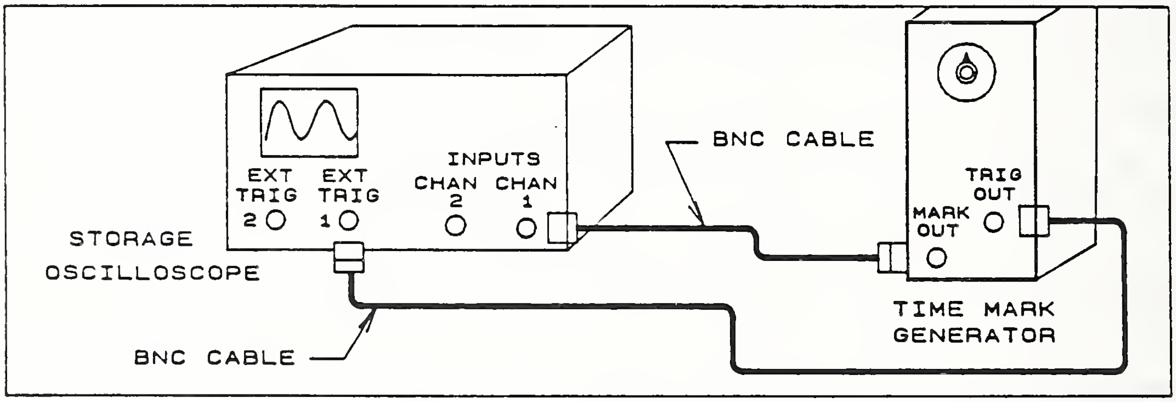


Figure 10.4.10.1 Test setup for the measurement of the time base accuracy

2. Set the range of the Channel 1 of the storage oscilloscope to 500 mV/cm and the sweep speed to 50 ns/div. The 50Ω termination should be ON.

3. Set the generator for a marker spacing of 50 ns. Position the marker pulses so that they approximately coincide with the vertical graticule lines.

4. Use the cursors in the delta time mode to measure the time between the 2nd and 10th time markers. Record the readout of this value into the appropriate row of the third column of table 10.4.10.1. This quantity is designated Tm. The actual marker spacing (400 ns in this case) is designated Tr.

5. Calculate the quantity (Tm-Tr) and enter the results in column 4 of table 10.4.10.1.

6. Repeat steps 4 and 5 for each of the sweep speeds and respective marker spacings indicated in table 10.4.10.1.

Table 10.4.10.1 Measurement of Time Base Accuracy

Sweep Speed T/div.	Marker Spacing Tr	Measured Spacing Tm	Difference (Tm-Tr)	Uncertainty in (Tm-Tr) (εr)	Specification Limits Min	Specification Limits Max
50 ns	400 ns	______ ns	______ ns	± 2.5 ns	-8 ns	+8 ns
100 ns	800 ns	______ ns	______ ns	± 5 ns	-16 ns	+16 ns
200 ns	1.6 μs	______ ns	______ ns	± 10 ns	-32 ns	+32 ns
500 ns	4 μs	______ ns	______ ns	± 25 ns	-80 ns	+80 ns
1μ	8 μs	______ ns	______ ns	± 50 ns	-160 ns	+160 ns
2 μs	16 μs	______ ns	______ ns	±100 ns	-320 ns	+320 ns
5 μs	40 μs	______ ns	______ ns	± 250 ns	-800 ns	+800 ns
10 μs	80 μs	______ μs	______ μs	± 0.5 μs	-1.6 μs	+1.6 μs
20 μs	160 μs	______ μs	______ μs	± 1 μs	-3.2 μs	+3.2 μs
50 μs	400 μs	______ μs	______ μs	± 2.5 μs	-8 μs	+8 μs
100 μs	800 μs	______ μs	______ μs	± 5 μs	-16 μs	+16 μs
200 μs	1.6 ms	______ μs	______ μs	± 10 μs	-32 μs	+32 μs
500 μs	4 ms	______ μs	______ μs	± 25 μs	-80 μs	+80 μs
1 ms	8 ms	______ μs	______ μs	± 50 μs	-160 μs	+160 μs
2 ms	16 ms	______ μs	______ μs	± 100 μs	-320 μs	+320 μs
5 ms	40 ms	______ μs	______ μs	± 250 μs	-800 μs	+800 μs
10 ms	80 ms	______ ms	______ ms	± 0.5 ms	-1.6 ms	+1.6 ms
20 ms	160 ms	______ ms	______ ms	± 1 ms	-3.2 ms	+3.2 ms
50 ms	400 ms	______ ms	______ ms	± 2.5 ms	-8 ms	+8 ms
100 ms	800 ms	______ ms	______ ms	± 5 ms	-16 ms	+16 ms
200 ms	1.600 s	______ ms	______ ms	± 10 ms	-32 ms	+32 ms
500 ms	4.00 s	______ ms	______ ms	± 25 ms	-80 ms	+80 ms

10.4.10.2 Time Base Uncalibrated Sweep Vernier

Specification:

The capability to provide uncalibrated sweep times in calibrated steps and up to 1.5 seconds per division shall be provided. This is not required for digital oscilloscopes.

[The specification is interpreted as: "The capability to provide uncalibrated sweep times for each calibrated sweep step up to 1.5 seconds per division shall be provided."]

Equipment:

Items	Model
Time Mark Generator	Tektronix TG 501 or equivalent
BNC Male to BNC Male Coaxial Cable 36 inches (91.4 cm)	Tektronix P/N 012-0482-00 or equivalent

Procedure:

1. Determine if the storage oscilloscope is a digital oscilloscope as defined in the NOTES, Item 9. If the oscilloscope is a digital oscilloscope, do not perform this test.

2. Check each range of the storage oscilloscope to assure that the capability to provide uncalibrated sweep times exists. Record the compliance (or lack of compliance) of this specification, for each range, in tables 10.4.10.2.

3. Set the controls of the storage oscilloscope to the default values given in NOTES, Item 4, p.1. Change the following controls from the default values to that shown below.

Vertical Controls (both channels)	
VOLTS/DIV	0.5 V
IMPEDANCE	50 Ω
Sweep Controls	
A TIME/DIVISION	0.5 s
VARIABLE VERNIER	On - set to provide the slowest sweep
Triggering Controls (both time bases)	
LEVEL	0.5 volts
TRIGGER MODE	Normal

4. Connect the equipment as shown below.

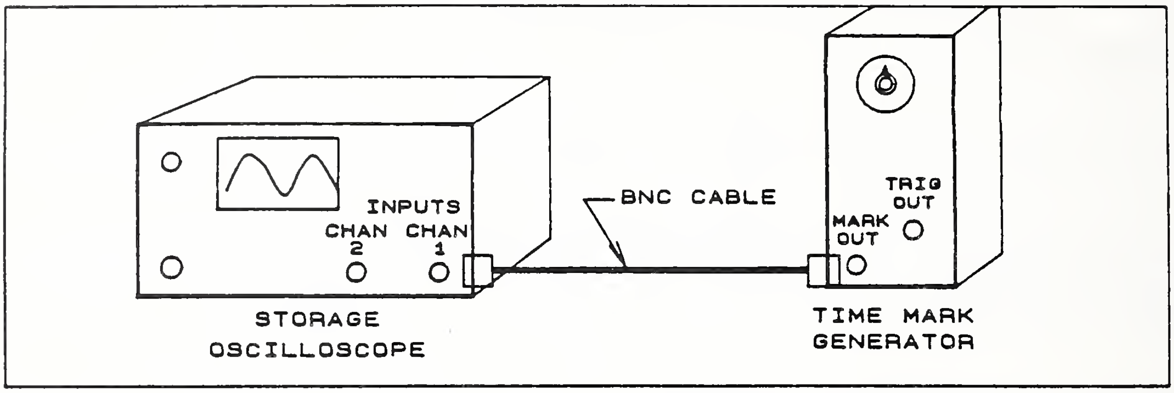


Figure 10.4.10.2 Test setup for demonstration of time base uncalibrated sweep vernier

5. Adjust the time mark generator to provide a marker output of one marker every five seconds.

6. Assure that the storage oscilloscope properly triggers on the first timing mark. If necessary, adjust the triggering controls to provide stable triggering on the positive slope of the time-mark pulse. (Initially, it may be useful to assure that the triggering is properly set using a faster sweep speed and time mark generator rate to provide a less "distracting" display. It has been noted that on some digital storage oscilloscopes, precise triggering is difficult to achieve at slow sweep speeds.)

7. Assure that at least 16 time mark pulses may be seen on the CRT display. The first time-mark pulse should be displayed on the left-hand side of the screen, the last time-mark pulse should be displayed just prior to the termination of the sweep. Record the compliance (or lack of compliance) of this specification in tables 10.4.10.2.

Table 10.4.10.2 Time Base Uncalibrated Sweep Vernier

Measurement Description	Measurement Data	Estimated Measurement Uncertainty	Specification Limits Min.	Max.	Units
0.5 s sweep uncalibrated?	____________	N/A	Yes		
0.2 s sweep uncalibrated?	____________	N/A	Yes		
0.1 s sweep uncalibrated?	____________	N/A	Yes		
50 ms sweep uncalibrated?	____________	N/A	Yes		
20 ms sweep uncalibrated?	____________	N/A	Yes		
10 ms sweep uncalibrated?	____________	N/A	Yes		
5 ms sweep uncalibrated?	____________	N/A	Yes		
2 ms sweep uncalibrated?	____________	N/A	Yes		
1 ms sweep uncalibrated?	____________	N/A	Yes		
500 μs sweep uncalibrated?	____________	N/A	Yes		
200 μs sweep uncalibrated?	____________	N/A	Yes		
100 μs sweep uncalibrated?	____________	N/A	Yes		
50 μs sweep uncalibrated?	____________	N/A	Yes		

Table 10.4.10.2 Time Base Uncalibrated Sweep Vernier - con't

Measurement Description	Measurement Data	Estimated Measurement Uncertainty	Specification Limits Min.	Max.	Units
20 μs sweep uncalibrated?	____________	N/A	Yes		
10 μs sweep uncalibrated?	____________	N/A	Yes		
5 μs sweep uncalibrated?	____________	N/A	Yes		
2 μs sweep uncalibrated?	____________	N/A	Yes		
1 μs sweep uncalibrated?	____________	N/A	Yes		
500 ns sweep uncalibrated?	____________	N/A	Yes		
200 ns sweep uncalibrated?	____________	N/A	Yes		
100 ns sweep uncalibrated?	____________	N/A	Yes		
50 ns sweep uncalibrated?	____________	N/A	Yes		
20 ns sweep uncalibrated?	____________	N/A	Yes		
10 ns sweep uncalibrated?	____________	N/A	Yes		
5 ns sweep uncalibrated?	____________	N/A	Yes		
Are 16 time marks visible?	____________	N/A	Yes		

10.4 Horizontal Section

10.4.11 Horizontal Linearity

Specification:

With one time mark per division displayed and the first and eleventh marks exactly on the first and eleventh vertical graticule lines, the marks in between shall coincide with their respective graticule lines to within ±0.25 minor divisions.

Equipment:

Items	Model
Time Mark Generator	Tektronix Model TG 501 or equivalent
Two 36" coaxial cables with male BNC connectors	Pomona BNC-C-36 or equivalent

Procedure:

1. Connect the time mark generator to the oscilloscope as shown in figure 10.4.11. Use either external or internal trigger, depending upon which mode works most effectively.

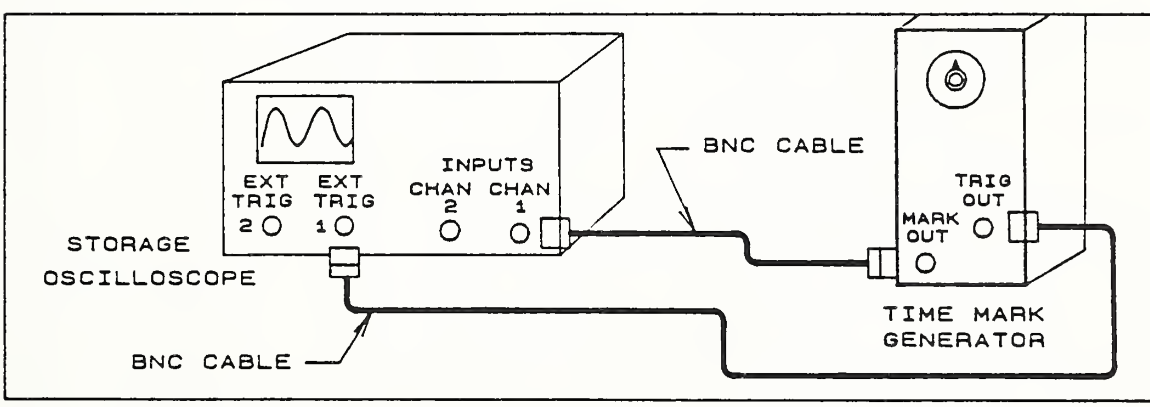


Figure 10.4.11 Test setup for measurement of horizontal linearity

2. Set the time-mark generator for a marker spacing of 50 ns, the sweep speed of the storage oscilloscope to 50 ns/div, and the range of Channel 1 to 500 mV/cm.

3. Vertically position the marker pulses so that the positive peaks just

4. Pull the center concentric (red) timing knob out on the time mark generator to facilitate variable timing adjustment. Using this control, as well as the scopes horizontal position control, adjust the marker spacing and position so that the first and eleventh marks exactly coincide with the first and eleventh vertical graticule lines.

5. Determine whether any time mark position is more than ±0.25 minor division from the associated vertical graticule. Indicate "yes" or "no" in column 3 of table 10.4.11. Also indicate which time mark(s) (if any) fall outside the specified limits.

6. Repeat steps 3 through 5 for each of the sweep speeds of the storage oscilloscope indicated in table 10.4.11.

Table 10.4.11. Horizontal Linearity Measurements

Sweep Speed T/Div.	Marker Spacing (Approx.)	Time Marks More Than ±0.25 Minor Div. From Grat. Line? Yes/No	Time Marks	Estimated Measurement Uncertainty	Specification Limits Min	Max
50 ns	50ns	______	______	± 2.5 ns	No	
100 ns	100ns	______	______	± 5 ns	No	
200 ns	200ns	______	______	± 10 ns	No	
500 ns	500ns	______	______	± 25 ns	No	
1 μs	1μs	______	______	± 50 ns	No	
2 μs	2μs	______	______	± 100 ns	No	
5 μs	5μs	______	______	± 250 ns	No	
10 μs	10μs	______	______	± 0.5 μs	No	
20μs	20μs	______	______	± 1 μs	No	
50μs	50μs	______	______	± 2.5 μs	No	
100μs	100μs	______	______	± 5 μs	No	
200μs	200μs	______	______	± 10 μs	No	
500μs	500μs	______	______	± 25 μs	No	
1ms	1ms	______	______	± 50 μs	No	
2ms	2ms	______	______	± 100 μs	No	
5ms	5ms	______	______	± 250 μs	No	
10ms	10ms	______	______	± 0.5 ms	No	
20ms	20ms	______	______	± 1 ms	No	
50ms	50ms	______	______	± 2.5 ms	No	
100ms	100ms	______	______	± 5 ms	No	
200ms	200ms	______	______	± 10 ms	No	
500ms	500ms	______	______	± 25 ms	No	

10.4.12 Delayed Time Base Capability or Equivalent Function

Specification:

A delayed time or equivalent capability shall be provided, with calibrated variable sweep times from 10 ns/div or less to 50 ms/div or more in at least a 5-2-1 sequence. This capability can be provided via the use of movable cursors, markers, or intensified zones to identify any portion of the waveform from the main sweep to be expanded.

Equipment:

Items	Model
Sine-Wave Generator	Tektronix SG 503 or equivalent
BNC Male to BNC Male Coaxial Cable 36 inches (91.4 cm)	Tektronix P/N 012-0482-00 or equivalent

Procedure:

1. Examine the storage oscilloscope to assure that that a delayed sweep or equivalent capability is provided with calibrated sweep times in accordance with the values given in tables 10.4.12.

2. Record the compliance (or lack of compliance) of this specification in tables 10.4.12.

3. Change the following controls to that shown below.

Vertical Controls	
IMPEDANCE	50 Ω
Sweep Controls	
HORIZONTAL DISPLAY	A Sweep Intensified by B
DELAY TIME	Set for zero time delay (or as near to zero as possible).
A TIME/DIVISION	0.1 μs
B TIME/DIVISION	10 ns
VARIABLE VERNIER	Off - at calibrated position
10X MAGNIFIER	Off

4. Connect the equipment as shown below.

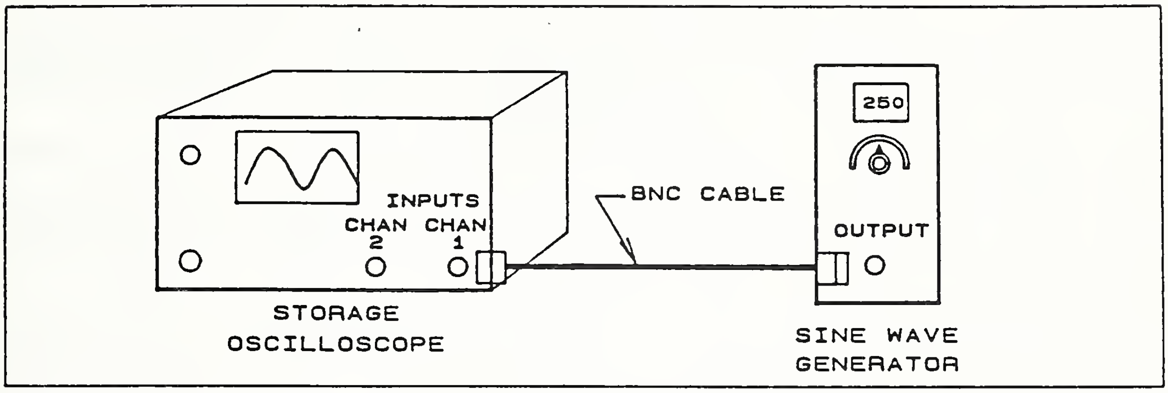


Figure 10.4.12 Test setup for demonstration of delayed time base capability or equivalent function

5. Adjust the sine-wave generator for an output of 2 V p-p at a frequency of 10 MHz.

6. Perform any minor adjustment to the storage oscilloscope to provide a stable display ten sine wave cycles.

7. Vary the DELAY TIME to assure that the movable cursors and/or an intensified zone may be displayed to identify any portion of the waveform. Record the compliance (or lack of compliance) of this specification in tables 10.4.12.

8. Change the following controls to that shown below.

Sweep Controls	
DELAY TIME	Set for zero time delay (or as near to zero as possible).
A TIME/DIVISION	100 μs
B TIME/DIVISION	50 μs

9. Adjust the sine-wave generator for an output of 1 V p-p at a frequency of 50 kHz.

10. Perform any minor adjustment to the storage oscilloscope to provide a stable display of a continuous train of sine waves.

11. Change the DELAY TIME to assure that the movable cursors and/or an intensified zone may be displayed to identify any portion of the waveform over either half of the display. Record the compliance (or lack of compliance) of this specification in tables 10.4.12.

Table 10.4.12 Delayed Time Base

Measurement Description	Measurement Data	Estimated Measurement Uncertainty	Specification Limits Min.	Max.	Units
50 ms sweep time exists?	______________	N/A	Yes		
20 ms sweep time exists?	______________	N/A	Yes		
10 ms sweep time exists?	______________	N/A	Yes		
5 ms sweep time exists?	______________	N/A	Yes		
2 ms sweep time exists?	______________	N/A	Yes		
1 ms sweep time exists?	______________	N/A	Yes		
500 μs sweep time exists?	______________	N/A	Yes		
200 μs sweep time exists?	______________	N/A	Yes		
100 μs sweep time exists?	______________	N/A	Yes		
50 μs sweep time exists?	______________	N/A	Yes		
20 μs sweep time exists?	______________	N/A	Yes		
10 μs sweep time exists?	______________	N/A	Yes		
5 μs sweep time exists?	______________	N/A	Yes		

Table 10.4.12 Delayed Time Base - con't

Measurement Description	Measurement Data	Estimated Measurement Uncertainty	Specification Limits Min.	Max.	Units
2 μs sweep time exists?	__________	N/A	Yes		
1 μs sweep time exists?	__________	N/A	Yes		
500 ns sweep time exists?	__________	N/A	Yes		
200 ns sweep time exists?	__________	N/A	Yes		
100 ns sweep time exists?	__________	N/A	Yes		
50 ns sweep time exists?	__________	N/A	Yes		
20 ns sweep time exists?	__________	N/A	Yes		
10 ns sweep time exists?	__________	N/A	Yes		
Delay time at 10 ns/div	__________	N/A	Yes		
Delay time at 50 ms/div	__________	N/A	Yes		
Cursors or zone at 10 MHz?	__________	N/A	Yes		
Cursors or zone at 50 kHz?	__________	N/A	Yes		
	__________				

10.4 Horizontal Section

10.4.12.1 Delayed Time Base Accuracy

Specification:

The delayed time base (or equivalent) accuracy shall be ±2 percent of the setting.

Equipment:

Items	Model
Time Mark Generator	Tektronix Model TG 501 or equivalent
Two 36" Coaxial Cables with male BNC connectors	Pomona BNC-C-36

Procedure:

1. Connect the time mark generator to the oscilloscope as shown in figure 10.4.12.1 on this measurement and following measurements, either internal or external trigger may be used. (On some waveforms, one may be more effective than the other.)

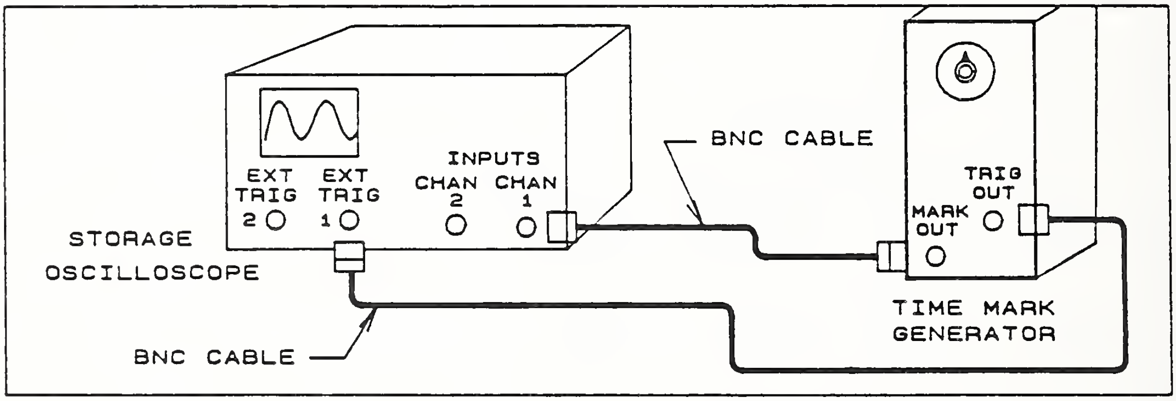


Figure 10.4.12.1 Test setup for measurement of delayed time base accuracy

2. Set the range of the Channel 1 of the storage oscilloscope to 500 mV/cm and the delayed sweep speed to 50 ns/div.

3. Set the generator for a marker spacing of 50 ns. Position the marker pulses so that they approximately coincide with the vertical graticule lines.

4. Use the cursors in the delta time mode to measure the time between the 2nd and 9th time markers. Record the readout of this value into the appropriate row of the third column of table 10.4.12.1. This quantity is designated Tm. The actual marker spacing (400 ns in this case) is designated Tr.

5. Calculate the quantity (Tm-Tr) and enter the results in column 4 of table 10.4.12.1.

6. Repeat steps 4 and 5 for each of the sweep speeds and respective marker spacings indicated in table 10.4.12.1.

Table 10.4.12.1 Measurement of Delayed Time Base Accuracy

Sweep Speed T/div.	Marker Spacing Tr	Measured Spacing Tm	Difference (Tm-Tr)	Uncertainty in (Tm-Tr) (ϵr)	Specification Limits Min	Max
50 ns	400 ns	______ ns	______ ns	± 2.5 ns	-8 ns	+8 ns
100 ns	800 ns	______ ns	______ ns	± 5 ns	-16 ns	+16 ns
200 ns	1.6 μs	______ ns	______ ns	± 10 ns	-32 ns	+32 ns
500 ns	4 μs	______ ns	______ ns	± 25 ns	-80 ns	+80 ns
1μ	8 μs	______ ns	______ ns	± 50 ns	-160 ns	+160 ns
2 μs	16 μs	______ ns	______ ns	± 100 ns	-320 ns	+320 ns
5 μs	40 μs	______ ns	______ ns	± 250 ns	-800 ns	+800 ns
10 μs	80 μs	______ μs	______ μs	± 0.5 μs	-1.6 μs	+1.6 μs
20 μs	160 μs	______ μs	______ μs	± 1 μs	-3.2 μs	+3.2 μs
50 μs	400 μs	______ μs	______ μs	± 2.5 μs	-8 μs	+8 μs
100 μs	800 μs	______ μs	______ μs	± 5 μs	-16 μs	+16 μs
200 μs	1.6 ms	______ μs	______ μs	± 10 μs	-32 μs	+32 μs
500 μs	4 ms	______ μs	______ μs	± 25 μs	-80 μs	+80 μs
1 ms	8 ms	______ μs	______ μs	± 50 μs	-160 μs	+160 μs
2 ms	16 ms	______ μs	______ μs	± 100 μs	-320 μs	+320 μs
5 ms	40 ms	______ μs	______ μs	± 25 μs	-800 μs	+800 μs
10 ms	80 ms	______ ms	______ ms	± 0.5 ms	-1.6 ms	+1.6 ms
20 ms	160 ms	______ ms	______ ms	± 1 ms	-3.2 ms	+3.2 ms
50 ms	400 ms	______ ms	______ ms	± 2.5 ms	-8 ms	+8 ms
100 ms	800 ms	______ ms	______ ms	± 5 ms	-16 ms	+16 ms
200 ms	1.600 s	______ ms	______ ms	± 10 ms	-32 ms	+32 ms
500 ms	4.00 s	______ ms	______ ms	± 25 ms	-80 ms	+80 ms

10.4 Horizontal Section

10.4.12.2 Delayed Time Base (or Equivalent) Horizontal Linearity

Specification:

Same as specified in Horizontal Linearity, Section 10.4.11.

Equipment:

Items	Model
Time Mark Generator	Tektronix Model TG 501 or equivalent
Two 36" coaxial cables with male BNC connectors	Pomona BNC-C-36 or equivalent

Procedure:

1. Connect the time mark generator to the oscilloscope as shown in figure 10.4.12.2. Use either external or internal trigger, depending upon which mode works most effectively.

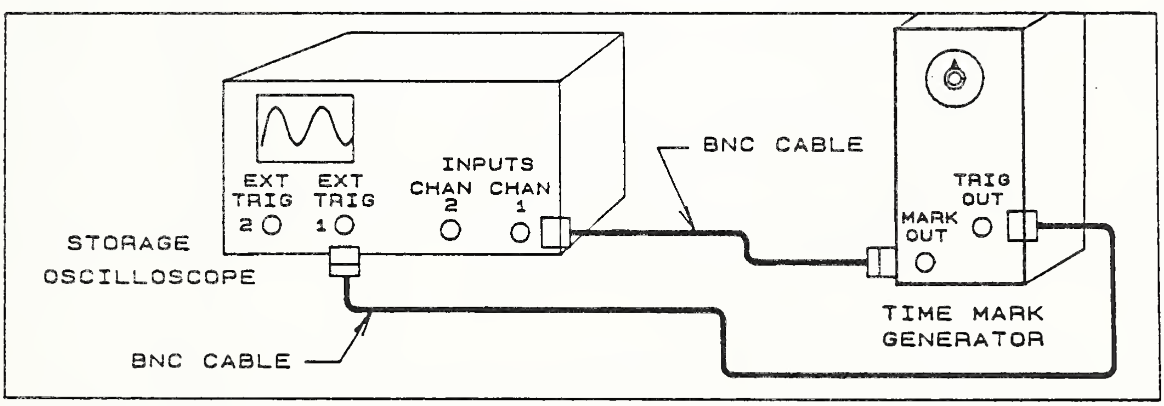


Figure 10.4.12.2 Test setup for measurement of delayed time base horizontal linearity

2. Set the time-mark generator for a marker spacing of 50 ns, the sweep speed of the storage oscilloscope to 50 ns/div, and the range of Channel 1 to 500 mV/cm.

3. Vertically position the marker pulses so that the positive peaks just reach the level of the center horizonal graticule line. (This line has minor division tick marks, which can help locate marker pulses.)

4. Pull the center concentric (red) timing knob out on the time mark generator to facilitate variable timing adjustment. Using this control, as well as the scopes horizontal position control, adjust the marker spacing and position so that the first and eleventh marks exactly coincide with the first and eleventh vertical graticule lines.

5. Determine whether any time mark position is more than ±0.25 minor division from the associated vertical graticule. Indicate "yes" or "no" in column 3 of table 10.4.12.2. Also indicate which time mark(s) (if any) fall outside the specified limits.

6. Repeat steps 3 through 5 for each of the sweep speeds of the storage oscilloscope indicated in table 10.4.12.2.

Table 10.4.12.2 Delayed Time Base Horizontal Linearity Measurements

Sweep Speed T/Div.	Marker Spacing (Approx.)	Time Marks More Than ±0.25 Minor Div. From Grat. Line? Yes/No	Time Marks	Estimated Measurement Uncertainty	Specification Limits Min	Max
50 ns	50ns	______	______	± 2.5 ns	No	
100 ns	100ns	______	______	± 5 ns	No	
200 ns	200ns	______	______	± 10 ns	No	
500 ns	500ns	______	______	± 25 ns	No	
1 μs	1μs	______	______	± 50 ns	No	
2 μs	2μs	______	______	± 100 ns	No	
5 μs	5μs	______	______	± 250 ns	No	
10 μs	10μs	______	______	± 0.5 μs	No	
20μs	20μs	______	______	± 1 μs	No	
50μs	50μs	______	______	± 2.5 μs	No	
100μs	100μs	______	______	± 5 μs	No	
200μs	200μs	______	______	± 10 μs	No	
500μs	500μs	______	______	± 25 μs	No	
1ms	1ms	______	______	± 50 μs	No	
2ms	2ms	______	______	± 100 μs	No	
5ms	5ms	______	______	± 250 μs	No	
10ms	10ms	______	______	± 0.5 ms	No	
20ms	20ms	______	______	± 1 ms	No	
50ms	50ms	______	______	± 2.5 ms	No	
100ms	100ms	______	______	± 5 ms	No	
200ms	200ms	______	______	± 10 ms	No	
500ms	500ms	______	______	± 25 ms	No	

10.4.12.3 Delayed Time Base Jitter

Specification:

Jitter shall be not greater than 1 part in 20,000 (0.005 percent) of the main time per division setting. This is not applicable for digital oscilloscopes.

Equipment:

Items	Model
Sine-Wave Generator	Tektronix SG 503 or equivalent
BNC Male to BNC Male Coaxial Cable 36 inches (91.4 cm)	Tektronix P/N 012-0482-00 or equivalent

Procedure:

1. Determine if the storage oscilloscope is a digital oscilloscope as defined in the NOTES, Item 9, p.3. If the oscilloscope is a digital oscilloscope, do not perform this test.

2. Change the following controls to that shown below.

Vertical Controls (both channels)

VOLTS/DIV	200 mV
IMPEDANCE	50 Ω

Sweep Controls

HORIZONTAL DISPLAY A Delayed by B	
DELAY TIME	Set for zero time delay (or as near to zero as possible).
A TIME/DIVISION	50 ns
B TIME/DIVISION	100 ns

3. Connect the equipment as shown below.

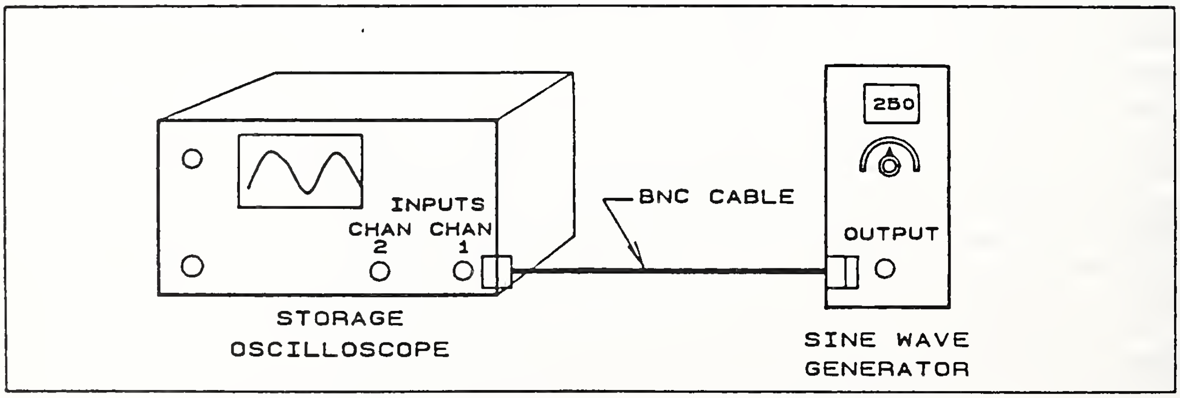


Figure 10.4.12.3 Test setup for measurement of delayed time base jitter

4. Adjust the sine-wave generator for an output of 5.5 V ac p-p at a frequency of 10 MHz.

5. Perform any minor adjustment to the storage oscilloscope to provide a stable display of the sine wave cycles.

6. Increase the DELAY TIME from 100 ns while observing the crossing point of the sine waves on the center horizontal cursor line. Continue to increase the DELAY TIME until the jitter of the crossing point equal one minor division or 10 ns. Record in table 10.4.12.3 the delay time where the jitter of the delayed sweep equals one minor division. Note: It may be necessary to perform this observation in a darkened room to observe the low duty-cycle display.

7. Convert the value of the delay time to ns and calculate the jitter as follows:

$$\text{Jitter} = \frac{\text{Time set on delayed time base (ns)}}{10 \text{ ns}}$$

8. Record the value of jitter in table 10.4.12.3.

Table 10.4.12.3 Delayed Time Base Jitter

Measurement Description	Measurement Data	Estimated Measurement Uncertainty	Specification Limits Min.	Max.	Units
Time set on delayed time base	____________	N/A	N/A	N/A	ns
Jitter	____________	±30 percent	20 000		

10.4 Horizontal Section

10.4.13 Trace Intensification or Markings

Specification:

The capability shall be provided to intensify or designate via cursors, the portion of the main time base which is to expand to full screen in the delayed time base.

Equipment:

Items	Model
Sine-Wave Generator	Tektronix SG 503 or equivalent
BNC Male to BNC Male Coaxial Cable 36 inches (91.4 cm)	Tektronix P/N 012-0482-00 or equivalent

Procedure:

1. Connect the output of the sine-wave generator to the CHANNEL 1 input of the storage oscilloscope as shown in the figure 10.4.13a.

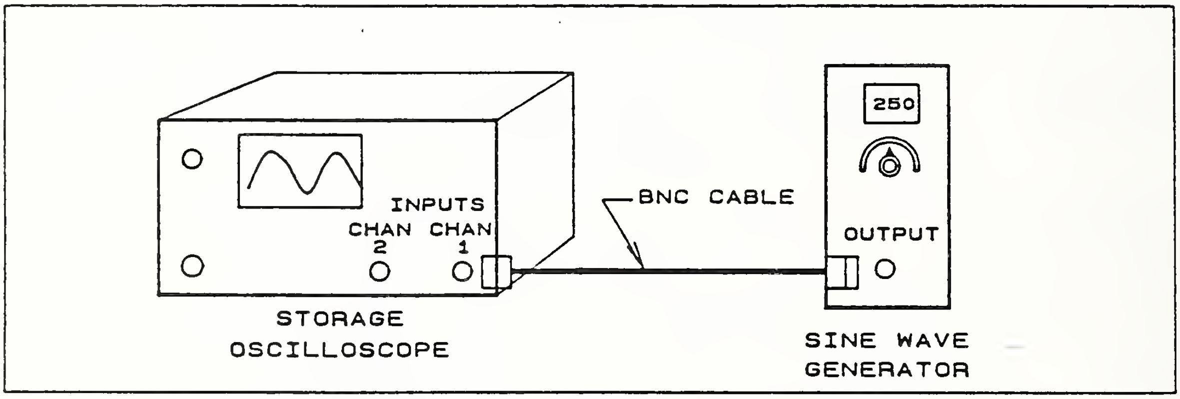


Figure 10.4.13a Test setup for measurement of trace intensification or marking

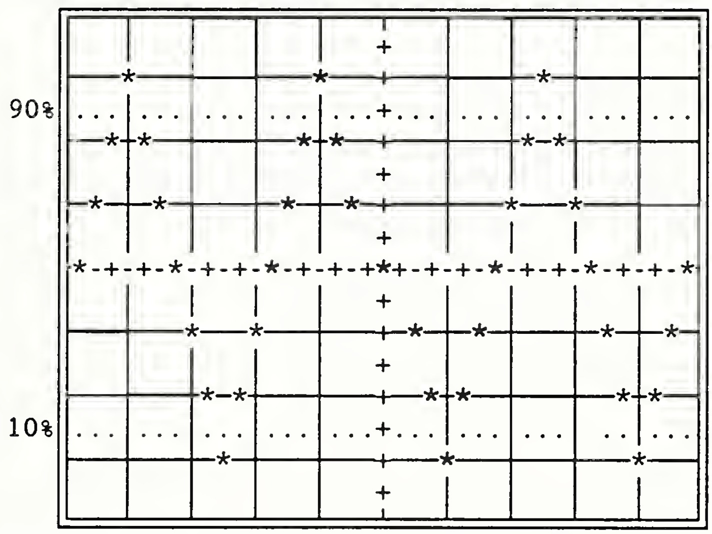
2. Adjust the output of the sine-wave generator for a 3.0 V peak-to-peak signal at a frequency of 50 kHz.

3. Set the controls of the storage oscilloscope to the default values given in NOTES, Item 4, p.1. Change the following controls from the default values to that shown below.

Vertical Controls (both channels)	
VOLTS/DIV	0.5 V
IMPEDANCE	50 Ω
Sweep Controls	
HORIZONTAL DISPLAY	Trace intensification
DELAY TIME	20 μs
B TIME/DIVISION	2 μs
A TIME/DIVISION	10 μs

4. Assure that for the trace intensification mode, the time base provides a display similar to that shown below. Record the compliance (or lack of compliance) of this specification in table 10.4.13.

This is a placekeeper only - actual display would show 5 cycles



The grid represents the graticule.

A display of a 50 kHz sine wave 3 V peak-to-peak showing trace intensification after 20 μs of the B sweep.

Figure 10.4.13b Display of trace intensification or markings (intensified B sweep)

5. Change the following control on the storage oscilloscope to the value shown below.

Sweep Controls	
HORIZONTAL DISPLAY	B Sweep

6. Assure that the A sweep shows the intensified portion of the sine wave signal as shown in figure 10.4.13b, above. The display should appear similar to that shown in the figure below. Record the compliance (or lack of compliance) of this specification in table 10.4.13.

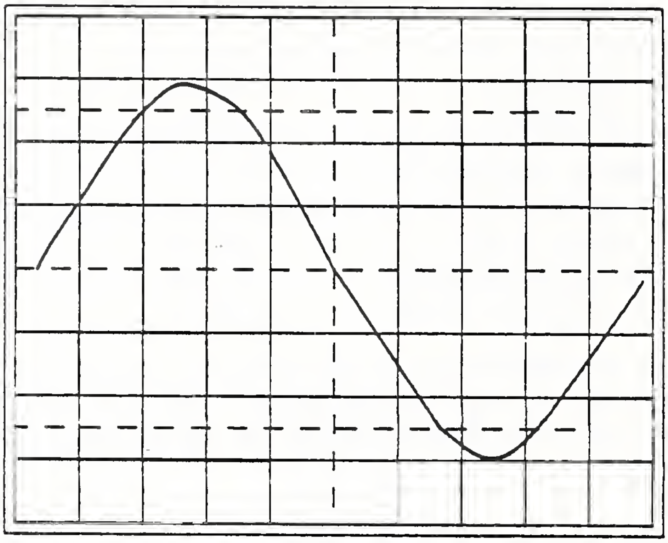


Figure 10.4.13c Display of trace intensification or markings - A sweep

Table 10.4.13 Trace Intensification or Markings

Measurement Description	Measurement Data	Estimated Measurement Uncertainty	Specification Limits Min.	Specification Limits Max.	Units
Sweep in normal mode?	______________	N/A	Yes		
Sweep in delay mode?	______________	N/A	Yes		

10.4 Horizontal Section

10.4.14 Horizontal Position Drift

Specification:

The CRT horizontal position drift with the horizontal magnifier in the X1 position shall not exceed 0.1 division per hour at any temperature between 0 degrees C and 55 degrees C.

Equipment:

Items	Model
Clock	General Electric 2908 or equivalent

Procedure:

1. Set the controls of the storage oscilloscope to the default values given in NOTES, Item 4, p.1. Change the following controls from the default values to that shown below.

   Sweep Controls
   HORIZONTAL DISPLAY X-Y Display

2. Carefully set the spot on the CRT such that it is coincident with the horizontal and vertical centerlines of the screen. Do not connect any cables to the vertical or horizontal input channels.

3. Record the time on the clock in table 10.4.14.

4. After one hour, read and record the time and the position of the beam on the horizontal axis of the CRT relative to the centerline of the screen in table 10.4.14.

Table 10.4.14 Horizontal Position Drift

Measurement Description	Measurement Data	Estimated Measurement Uncertainty	Specification Limits Min.	Max.	Units
Start Time	________				
Ending Time	________				
Horizontal Drift	________	±0.05		0.1	div

10.4 Horizontal Section

10.4.15 Time Base Mode

Specification:

The equipment shall be capable of providing the following time base modes:

a. *Normal Sweep. This mode shall permit operation in the normal undelayed manner.*

b. *Delayed sweep or equivalent. This mode shall permit the generation of a sweep after a defined interval of delay following the trigger pulse. This [mode] shall provide the ability to display the main sweep and the delayed sweep simultaneously on the display.*

Equipment:

Items	Model
Sine-Wave Generator	Tektronix SG 503 or equivalent
BNC Male to BNC Male Coaxial Cable 36 inches (91.4 cm)	Tektronix P/N 012-0482-00 or equivalent

Procedure:

1. Connect the output of the sine-wave generator to the CHANNEL 1 input of the storage oscilloscope as shown in figure 10.4.15a.

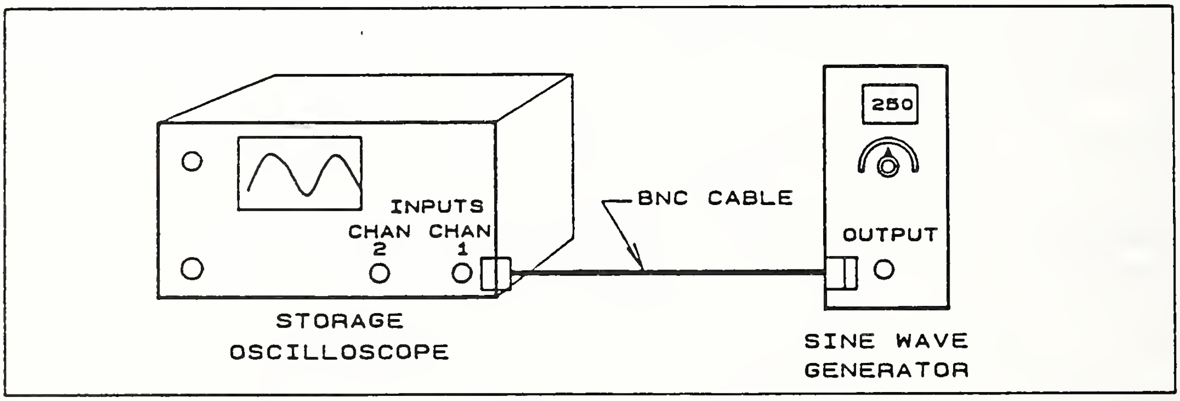


Figure 10.4.15a Test setup for demonstration of time base mode

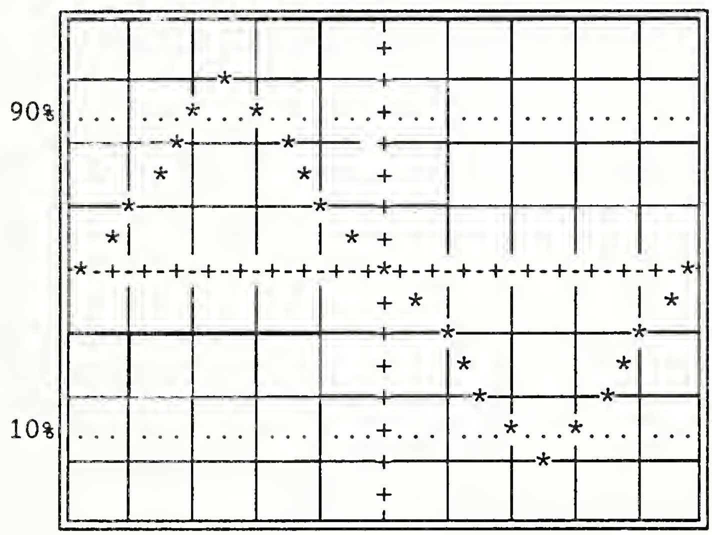
2. Adjust the output of the sine-wave generator for a 3.0 V peak-to-peak signal at a frequency of 50 kHz.

3. Set the controls of the storage oscilloscope to the default values given in NOTES, Item 4, p.1. Change the following controls from the default values to that shown below.

Vertical Controls (both channels)	
VOLTS/DIV	0.5 V
IMPEDANCE	50 Ω
Sweep Controls	
HORIZONTAL DISPLAY	A Sweep
A TIME/DIVISION	2 μs
B TIME/DIVISION	2 μs

4. Assure that for the normal sweep mode, the time base provides a display similar to that shown in figure 10.4.15b. Record the compliance (or lack of compliance) of this specification in table 10.4.15.

This is a placekeeper only



The grid represents the graticule.

A display of a 50 kHz sine wave 3 V peak-to-peak at a sweep speed of 2μs per major division.

Figure 10.4.15b Display of time base mode (normal)

5. Change the following controls on the storage oscilloscope to the values shown below.

Sweep Controls	
HORIZONTAL DISPLAY	Delayed Sweep (or equivalent)
B TIME/DIVISION	2 μs
A TIME/DIVISION	5 μs

6. Assure that for the delayed sweep mode (or equivalent), the time base provides a display similar to that shown in figure 10.4.15c. Record the compliance (or lack of compliance) of this specification in table 10.4.15.

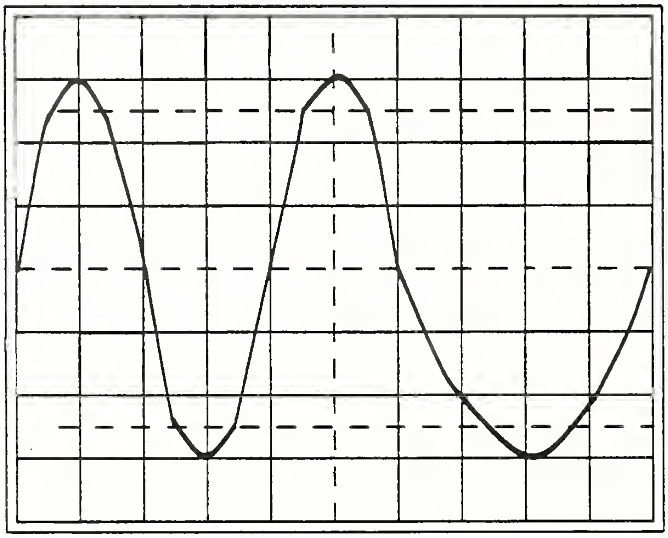


Figure 10.4.15c Display of time base mode (delayed sweep or equivalent)

Table 10.4.15 Time Base Mode

Measurement Description	Measurement Data	Estimated Measurement Uncertainty	Specification Limits Min.	Specification Limits Max.	Units
Sweep in normal mode?	____________	N/A	Yes		
Sweep in delay mode?	____________	N/A	Yes		

10.4 Horizontal Section

10.4.16 Main Time Base Uncalibrated Sweep Vernier Indicator

Specification:

An indicator shall be provided to indicate when the main time base vernier is not in the calibrated position. This is not required for digital oscilloscopes.

Equipment:

Items	Model
None	

Procedure:

1. Determine if the storage oscilloscope is a digital oscilloscope as defined in the NOTES, Item 9, p.3. If the oscilloscope is a digital oscilloscope, do not perform this test.

2. Set the main TIME BASE VERNIER in the uncalibrated position.

3. Assure that an indicator designates that the main time base is in the uncalibrated position. Record the compliance (or lack of compliance) of this specification in table 10.4.16.

Table 10.4.16 Main Time Base Uncalibrated Sweep Vernier Indicator

Measurement Description	Measurement Data	Estimated Measurement Uncertainty	Specification Limits Min.	Specification Limits Max.	Units
Indicator for uncal. sweep?	________	N/A	Yes		

10.4 Horizontal Section

10.4.17 Variable Sweep Delay Time

Specification:

A 20 nsec or less to 0.5 seconds or more delay time control shall be provided.

Equipment:

Items	Model
None	

Procedure:

Note: The range and accuracy of the sweep delay time control is verified in paragraph 10.4.12 and its subparagraphs. Passage of these paragraphs constitutes passage of this specification.

1. Assure that a sweep delay time control is provided on the storage oscilloscope. Record the compliance (or lack of compliance) of this specification in table 10.4.17.

2. Assure that the minimum sweep delay time is 20 ns or less. Record the compliance (or lack of compliance) of this specification in table 10.4.17.

3. Assure that the maximum sweep delay time is 0.5 s or more. Record the compliance (or lack of compliance) of this specification in table 10.4.17.

Table 10.4.17 Variable Sweep Delay Time

Measurement Description	Measurement Data	Estimated Measurement Uncertainty	Specification Limits Min.	Specification Limits Max.	Units
A variable sweep delay time control provided?	____________	N/A	Yes		
Minimum delay	____________	N/A		20	ns
Maximum delay	____________	N/A	0.5		s

10.4 Horizontal Section

10.4.18 Horizontal Position

Specification:

A horizontal position control shall be provided to move the left hand end of the trace to the right past the center graticule line and the right hand end of the trace to the left past the center graticule line. This is not required for digital oscilloscopes.

Equipment:

Items	Model
None	

Procedure:

1. Determine if the storage oscilloscope is a digital oscilloscope as defined in the NOTES, Item 9, p.3. If the oscilloscope is a digital oscilloscope, do not perform this test.

2. Assure that, by the adjustment of the HORIZONTAL POSITION control, the left-hand end of the trace may be moved to the right past the center graticule line. Record the compliance (or lack of compliance) of this specification in table 10.4.18.

3. Assure that, by the adjustment of the HORIZONTAL POSITION control, the left-hand end of the trace may be moved to the left past the center graticule line. Record the compliance (or lack of compliance) of this specification in table 10.4.18.

Table 10.4.18 Horizontal Position

Measurement Description	Measurement Data	Estimated Measurement Uncertainty	Specification Limits Min.	Max.	Units
Correct pos. to right?	________	N/A	Yes		
Correct pos. to left?	________	N/A	Yes		

10.4 Horizontal Section

10.4.19 Reset Single Sweep Operation

Specification:

A reset feature shall be provided to arm the sweep while in single sweep and provide an indicator when the oscilloscope is armed and in the single shot operation mode.

Equipment:

Items	Model
Time Mark Generator	Tektronix TG 501 or equivalent
BNC Male to BNC Male Coaxial Cable 36 inches (91.4 cm)	Tektronix P/N 012-0482-00 or equivalent

Procedure:

1. Connect the MARKER OUT of the time mark generator to the CHANNEL 1 input of the storage oscilloscope as shown in the figure 10.4.19a.

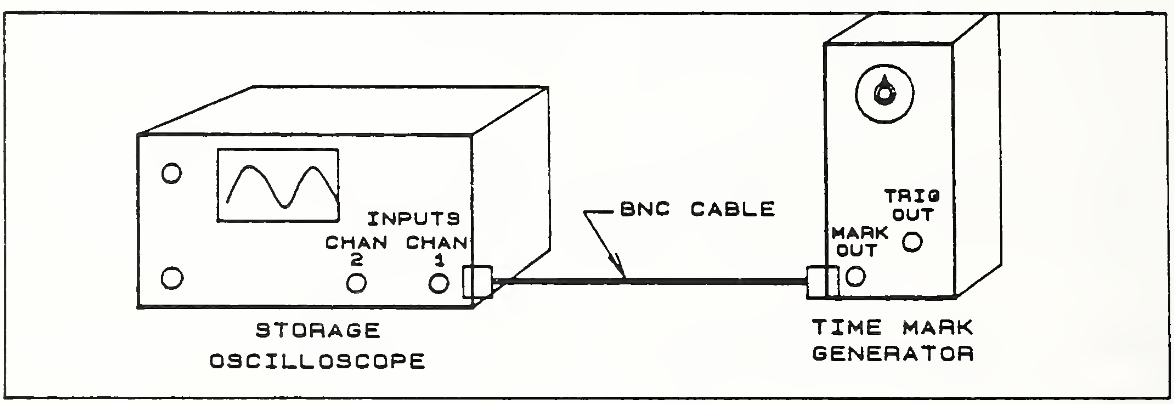


Figure 10.4.19 Test setup for demonstration of single sweep operation

2. Set the controls of the storage oscilloscope to the default values given in NOTES, Item 4, p.1. Change the following controls from the default values to that shown below.

Triggering Controls (both time bases)	
LEVEL	0.2 V
Sweep Controls	
A TIME/DIVISION	100 ms

3. Adjust the MARKER rate control of the time mark generator to provide 1 mark per second.

4. Make any minor adjustments of the oscilloscope settings to assure a clear, stable display that shows the rise and exponential decay of the time mark at approximately 1 second intervals.

5. Disconnect the cable from the MARKER OUT of the time mark generator.

6. Change the following controls from the default values to that shown below.

Triggering Controls	(both time bases)
TRIGGER MODE	Single Sweep

7. Arm the sweep by pressing the RESET or acquire push button. Assure that a lamp indicates that the sweep is armed or ready. Record the compliance (or lack of compliance) of this specification in table 10.4.19.

8. Plug the cable into the MARKER OUT connector of the time mark generator.

9. Assure that the storage oscilloscope provides a single sweep of the CRT display within approximately 1 second. Record the compliance (or lack of compliance) of this specification in table 10.4.19.

10. Assure that a lamp indicates that the sweep is not armed. Record the compliance (or lack of compliance) of this specification in table 10.4.19.

Table 10.4.19 Reset Push Button and Lamp

Measurement Description	Measurement Data	Estimated Measurement Uncertainty	Specification Limits Min.	Specification Limits Max.	Units
Indicates armed sweep?	____________	N/A	Yes		
Provides single sweep?	____________	N/A	Yes		
Indicates un-armed sweep?	____________	N/A	Yes		

10.5 Controls Location

Specification:

All operator controls and indicators shall be provided on the front panel.

Equipment:

Items	Model
None	

Procedure:

1. Assure that all operational controls are provided on the front panel. If access to any controls or indicators on other than the front panel of the storage oscilloscope was required in the execution of these Performance Tests, the storage oscilloscope does not comply with this specification. Record the compliance (or lack of compliance) of this specification in table 10.5.

Table 10.5 Controls Location

Measurement Description	Measurement Data	Estimated Measurement Uncertainty	Specification Limits Min.	Specification Limits Max.	Units
All controls on front?	________	N/A	Yes		

10.6 Waveform Storage

Specification:

The equipment shall be capable of capturing and storing a displayed waveform for a minimum viewing time of 15 minutes.

Equipment:

Items	Model
Clock	General Electric 2908 or equivalent
Sine-Wave Generator	Tektronix SG 503 or equivalent
BNC Male to BNC Male Coaxial Cable 36 inches (91.4 cm)	Tektronix P/N 012-0482-00 or equivalent

Procedure:

1. Connect the output of the sine-wave generator to the CHANNEL 1 input of the storage oscilloscope as shown in the figure 10.6.

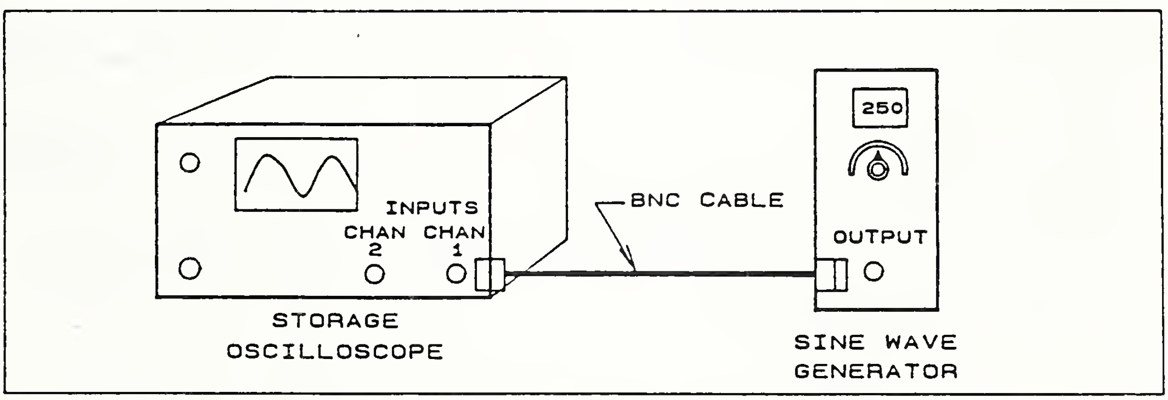


Figure 10.6 Test setup for demonstration of waveform storage

2. Set the controls of the storage oscilloscope to the default values given in NOTES, Item 4, p.1. Change the following controls from the default values to that shown below.

   Vertical Controls (both channels)
   IMPEDANCE 50 Ω

3. Adjust the output of the sine-wave generator for a 5 V ac (rms) signal at a frequency of 1 MHz.

4. Make any minor adjustments of the oscilloscope settings to assure a clear, stable display. Command the storage oscilloscope to acquire the display.

5. Read the time on the clock and record the time in table 10.6.

6. After 15 minutes has elapsed, again record the time in table 10.6.

7. Assure that equipment shall be capable of capturing and storing a displayed waveform. Record the compliance (or lack of compliance) of this specification in table 10.6.

8. Connect the output of the sine-wave generator to the CHANNEL 2 input of the storage oscilloscope.

9. Repeat steps 4 through 7 for CHANNEL 2.

Table 10.6 Waveform Storage

Measurement Description	Measurement Data	Estimated Measurement Uncertainty	Specification Limits Min.	Max.	Units
Channel 1 Start Time	______				
End Time	______				
Captures waveform?	______	N/A	Yes		
Channel 2 Start Time	______				
End Time	______				
Captures Waveform?	______	N/A	Yes		

10.6 Waveform Storage

10.6.1 Single Shot Response

Specification:

Equipment shall be capable of displaying and storing an 8 division high single shot input pulse rise time of 70 ns. Accuracy shall be within ± 2% of full-scale amplitude and ±1.4 ns.

Equipment:

Items	Model
Pulse Generator with adjustable rise time	Hewlett-Packard Model 8082A
BNC male to BNC male coaxial cable, 3 feet long	RG-58/U

Procedure:

1. Connect the pulse generator output to Channel 1 of the storage oscilloscope as shown in figure 10.6.1.

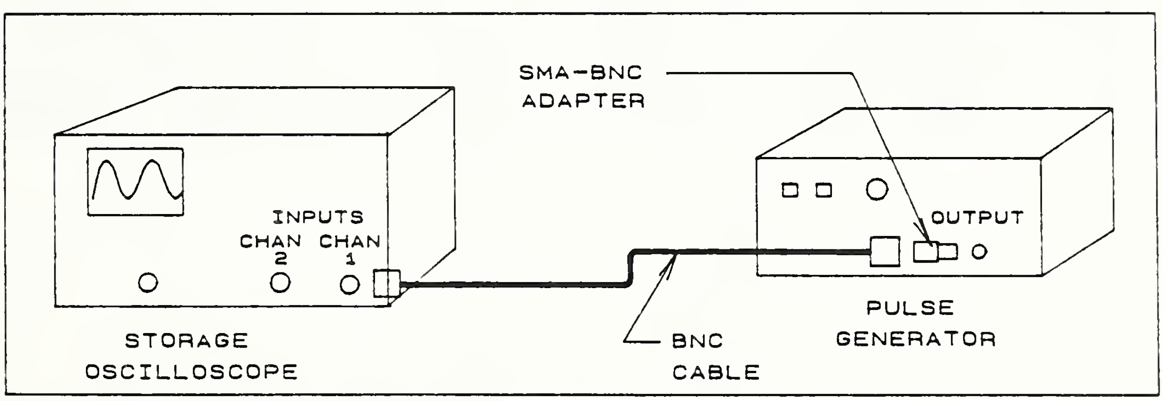


Figure 10.6.1. Setup for the measurement of the single shot response

2. Set the pulse generator for a pulse period of approximately 1 microsecond and a pulse width of about 300 nanoseconds. Select a positive output polarity. Set the pulse generator amplitude to the 1 V range for a 50 Ω load and set the vernier to approximately mid-scale.

3. Set the storage oscilloscope sweep speed to 200 ns/cm and Channel 1 to the 100 mV/div range. Set the input coupling to dc 50Ω ON.

4. Adjust the pulse generator amplitude vernier and offset to display a peak-to-peak amplitude of ±4 div (±400mV). If the pulses have baseline and/or top-line slopes, use the midpoints of these lines to adjust the pulse height for exactly 8 cm deflection. The storage oscilloscope vertical position control may be used for fine position adjustment of the waveform.

5. Set the storage oscilloscope in the repetitive mode, and use the cursors in the delta voltage mode to measure the amplitude between the midpoints of the base line and top line of a pulse. Record the readout into column 1 of table 10.6.1a. This quantity is designated Vr.

6. Set the trigger circuit of the oscilloscope in the single sequence (single shot mode). As before, use the cursors to measure the amplitude of the single acquisition. Record the readout into column 2 of the table. This quantity is designated Vs. Calculate the quantity (Vs-Vr) and enter into column three of table 10.6.1a.

7. Select the repetitive mode of operation for the storage oscilloscope and carefully set the p-p amplitude to exactly ±4 div of deflection. Change the sweep speed to 10 ns/div. Next, carefully adjust the rise time of the pulse generator for 70 ns. This can be facilitate by adjusting the horizontal position of the waveform and the rise time so that the -3.2 division point of the voltage step coincides with the <u>first</u> vertical graticule line and the +3.2 division point of the voltage step coincides with the <u>eighth</u> vertical graticule line. Enter 70 ns into the first column of table 10.6.1.b. This quantity is designated $(T_R)_r$.

8. Set the oscilloscope trigger circuit for single shot (single sequence) operation and make a single acquisition. Use the cursors in the delta time mode and position them to pass through the -3.2 cm and +3.2 cm amplitude points of the voltage step. Record the readout in the second column of table 10.6.1.b. This quantity is designated $(T_R)_s$. Calculate $(T_R)_s-(T_R)_r$ and enter into the third column of table 10.6.1b.

Table 10.6.1a Single Shot Response Measurement of Gain Accuracy

Peak-to-Peak Amplitude (mV) Repetitive Mode (Vr)	Single Shot (Vs)	Amplitude Difference (mV) (Vs-Vr)	Measurement Uncer- tainty	Specification Limits Min	Max
			±7 mV	-16 mV	+16 mV

Table 10.6.1b Single Shot Response Measurement of Rise Time

Risetime (ns) Repetitive Mode $(T_R)_r$	Single Shot $(T_R)_s$	Difference in Risetimes (mV) $(T_R)_s - (T_R)_r$	Measurement Uncer- tainty	Specification Limits Min	Max
			±1 ns	-1.4 ns	+1.4 ns

10.6 Waveform Storage

10.6.2 Sampling Rate

Specification:

If digital storage is used, then the equipment shall be capable of sampling at a rate of 100 megasamples per second or more, on both channels simultaneously.

Equipment:

Items	Model
Sine-wave Generator	Tektronix SG503 or equivalent
Two 36" Coaxial Cable (male BNC connectors)	Tektronic P/N 012-0482-00 or equivalent
Signal Splitter	NIST Supplied

Procedure:

1. Refer to figure 10.6.2. Set the frequency of the sine-wave generator to 5 MHz and its amplitude to a minimum value. Connect the signal splitter directly to the generator output, and use the cables to connect the signal splitter to the two inputs of the oscilloscope.

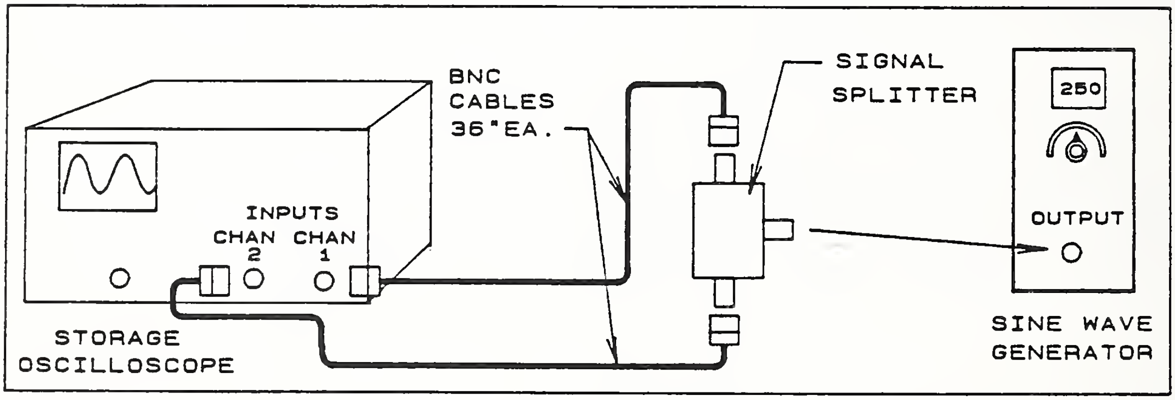


Figure 10.6.2 Test setup for verifying sampling rate of 100 MHz or greater, on both channels simultaneously

2. Set the range of both channels to 500 mV/div and set the coupling for both channels to DC coupling and 50 Ω ON. Position the horizontal traces approximately ± 1 1/2 divisions from the center horizontal graticule line.

3. Adjust the sine-wave generator for a displayed amplitude of 1.5 V p-p. The observed amplitude should be essentially the same on both channels. (Use oscilloscope in repetitive mode.)

4. Next, set the trigger circuit of the oscilloscope in the single sequency (single shot) mode. Press the ACQUIRE button, or appropriate control, for each single shot acquisition desired.

5. Adjust the frequency of the sine-wave generator as indicated in the following paragraph. Do not change the amplitude from the 1.5 V p-p value. For all input frequencies within the pass band of the vertical amplifiers, the displayed waveforms for the channels should be essentially the same. Also the phase difference should be negligible.

6. Indicate in table 10.6.2 the observed waveforms resulting from adjusting the generator frequency as follows:

   (a) 5 MHz. The waveforms should be of good quality.

   (b) 50 MHz, or one-half the sampling rate. The amplitude should fluctuate considerably.

   (c) 90 MHz. If the sampling frequency is less than twice 90 MHz, you should see the difference frequency, i.e., sampling frequency - 90 MHz. If the sampling frequency is greater than 180 MHz, you should see a 90 MHz frequency.

Table 10.6.2 Sampling Rate. Observed Waveforms Using Single-shot Acquisitions, Both Channels ON. All Frequencies in MHz.

Sampling Freq. (Mfr's. spec.) Fs	Input Frequency	Observed Frequency	Waveform Same for Both Channels?		Phase Difference Negligible?	
			Yes	No	Yes	No
	5					
	50 or Fs/2					
	90					

10.7 Calibrator

<u>Specification:</u>

A square wave calibrator signal shall be provided through a connector mounted on the front panel. The connector shall be compatible with a probe tip supplied. The calibrator shall be short circuit proof.

<u>Equipment</u>:

Items	Model
Clock	Commercial item
Probe, 10:1	Supplied by Manufacturer

<u>Procedure</u>:

1. Assure that a calibration signal is provided through a connector on the front panel of the storage oscilloscope. Record the compliance (or lack of compliance) of this specification in table 10.7.

2. Connect the probe to the CHANNEL 1 input of the storage oscilloscope and display the calibration signal. If more than one level of calibration signal is provided, select the signal with the greatest peak-to-peak amplitude. The display should be a square wave. Record the compliance (or lack of compliance) of this specification in table 10.7. Record the amplitude of the square wave in table 10.7.

3. Short circuit the output of the calibrator. After 5 minutes has elapsed, note any evidence of smoking, arcing, or charring of the storage oscilloscope. Record the result in table 10.7.

4. Repeat step 2 to assure that the short circuit has not drastically altered the performance of the calibrator and enter the results in table 10.7.

Table 10.7 Calibrator

Measurement Description	Measurement Data	Estimated Measurement Uncertainty	Specification Limits Min.	Max.	Units
Connector on front panel?	____________	N/A	Yes		
Square-wave output?[1]	____________	N/A	Yes		
Peak-to-peak amplitude	____________				V
Damage during short circuit	____________	N/A	No		
Square-wave output?[1]	____________	N/A	Yes		
Peak-to-peak amplitude?	____________				V

1. Also, the appearance of a frozen non-triggered horizontal line stored from the previous acquisition is acceptable.

APPENDIX C

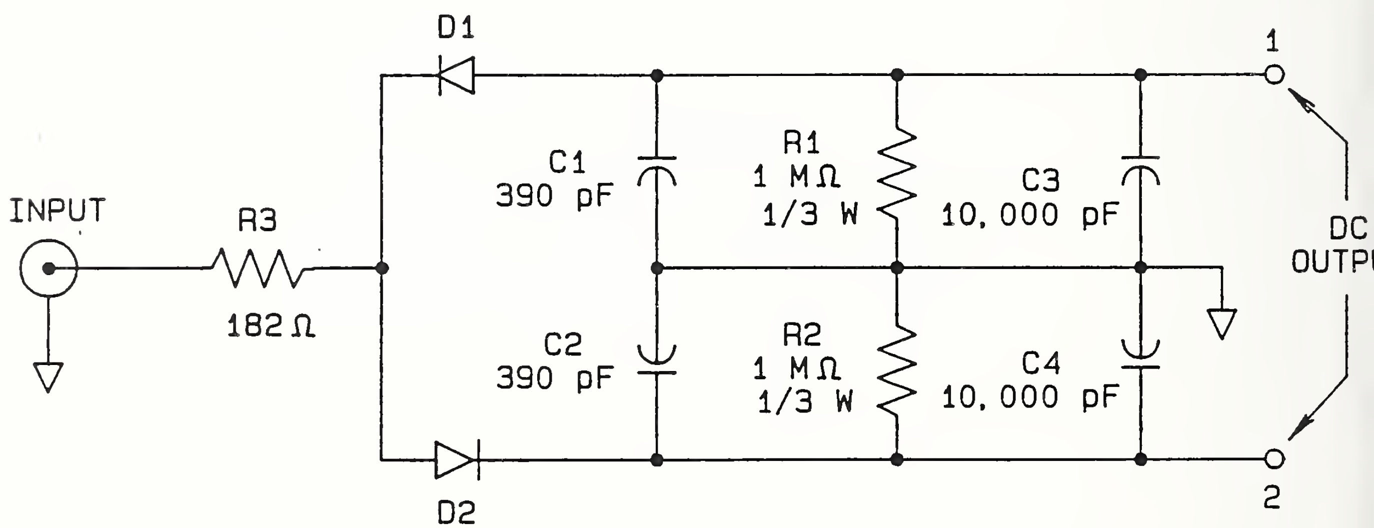
SPECIAL FIXTURES USED IN TEST PROCEDURES

FOR THE OS-291/G STORAGE OSCILLOSCOPE

Peak-to-Peak Detector

The peak-to-peak detector (Figure C-1) functions as follows: For ideal diodes, C1 and C3 charge through D1 to the peak value of the negative half cycles, and capacitors C2 and C4 charge through D2 to the peak value of the positive half cycles. Since the time constants (C1 + C3)R1 and (C2 + C4)R2 are approximately 0.01 s, the output ripple is negligible above 0.5 MHz, and the voltage across C1 and C3 equals the peak value of the negative half cycle and the voltage across C2 and C4 equals the peak value of the positive half cycles. Thus, the DC output equals the p-p value of the sine wave input.

In practice diodes D1 and D2 are not ideal but have an effective forward voltage drop of about 0.6V. Therefore, the dc output voltage is less than the p-p input voltage by about 1.2V. This subtraction, however, is approximately constant for all frequencies in the 0.5 - 100 MHz range. Therefore, the diode forward voltage drops do not affect the frequency response measurements.



NOTES:
D1 & D2 ARE MOTOROLA MMBD701
C1 & C2 ARE MICA
C3 & C4 ARE CERAMIC DISC
TERMINALS 1 & 2 ARE FLOATING RELATIVE TO GROUND (⏚)

Figure C-1. Peak-peak voltage detector. The DC OUTPUT is connected to a dc DVM with floating input terminals. R3, D1 D2, C1 and C2 are mounted with short leads in Pomona box #3751. The remaining parts are mounted outside the box and connected between ground and the feed through pins, 1 and 2. The input connector is a female BNC.

50 Ohm, 40 Watt Terminator

The terminator shown in figure C-2 is used to terminate the output of the rf power amplifier shown in figure 3.3 of the main text. Its physical and electrical description is given in the caption of figure C-2.

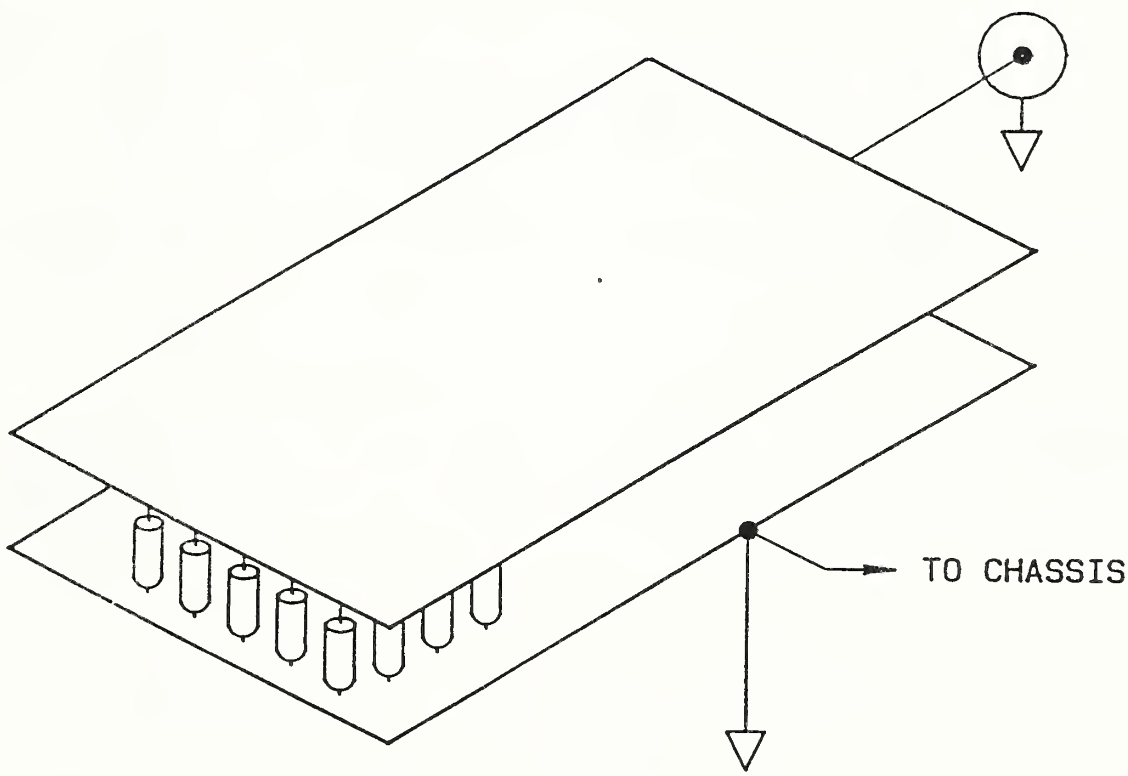


Figure C-2. Construction of 50 Ω, 40 W terminator. Twenty 1 kΩ resistors (2 W) are mounted between two flat copper plates, and this assembly is mounted in a 105 mm x 68 mm x 42 mm Al. box (Pomona part #3302). The connector (female BNC) is mounted on one side of the box, with its center pin connected to the ungrounded plate.

Trace Rotation Alignment Tool

This tool is shown in figure C-3.

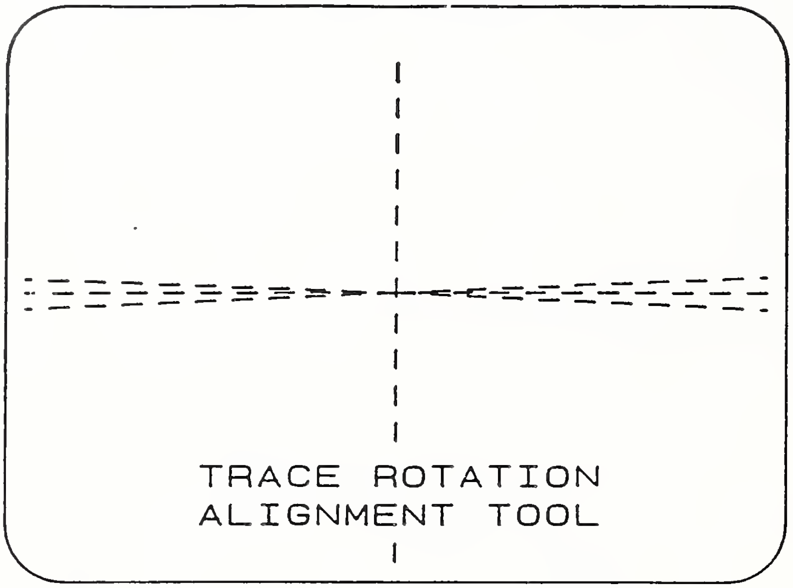


Figure C-3. Mylar overlay used for measurement of trace rotation about scope's horizontal axis.

Attenuator, 10:1

The voltage divider shown in figure C-4 is mounted in a 38 mm x 29 mm x 22 mm aluminum box (Pomona part number 3752). The output connector is usually attached directly to the scope input connector. For a scope input capacitance of 20 pF, the attenuation changes no more than ± 0.022 % for frequencies out to 200 kHZ.

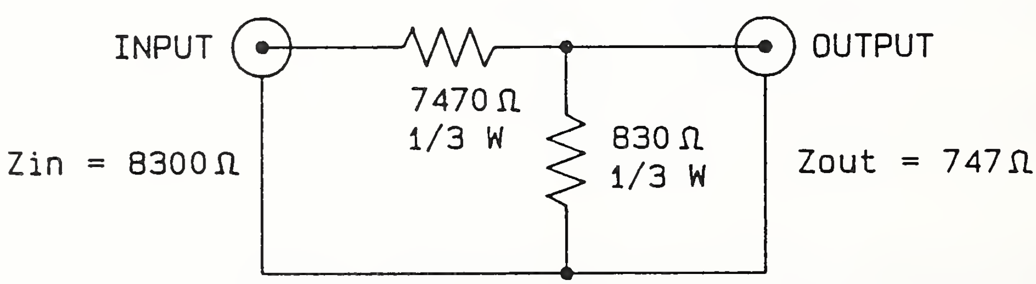


Figure C-4. 10:1 attenuator. The divider ratio is 10:1 to within ± 0.035 %. BNC female and male connectors are used for the input and output connectors, respectively.

Signal Splitter

This device is described in figure C-5, shown below.

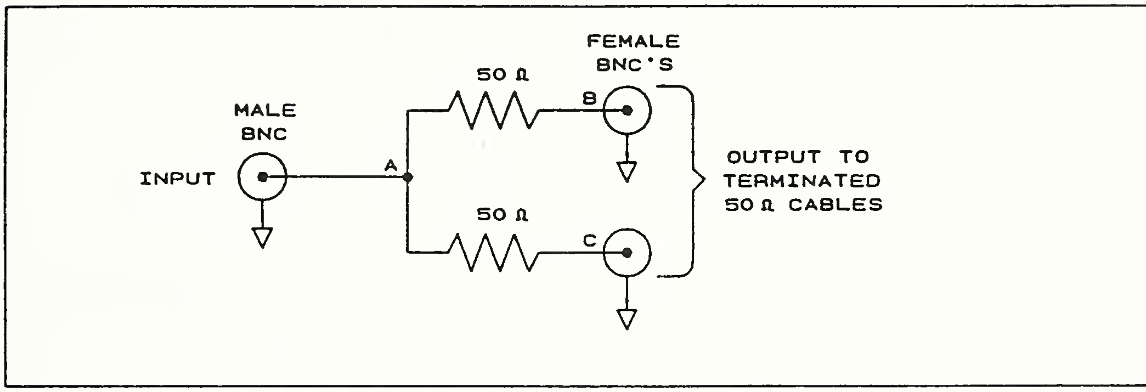


Figure C-5. Signal Splitter. Signals at B and C have the same phase and have one-half the amplitude as the signal at A. The connectors and resistors are mounted on/in a 38 mm x 29 mm x 23 mm aluminum box (modified Pomona 3751 box).

APPENDIX D

TEST EQUIPMENT

FOR THE OS-291/G STORAGE OSCILLOSCOPE

Test equipment for the OS-291/G Storage Oscilloscope

Equipment:

Items	Model
Precision Optical Comparator (15X)	Bishop Model 3561 or equivalent
Sine-Wave Generator	Tektronix SG 503 or equivalent
BNC Male to BNC Male Coaxial Cable 36 inches (91.4 cm)	Tektronix P/N 012-0482-00 or equivalent
Trace Rotation Alignment Tool	NIST supplied
Time Mark Generator	Tektronix TG 501 or equivalent
DC Voltage Calibrator	Fluke Model 5101B or equivalent
BNC Female to Banana Adapter	Pomona 1452 or equivalent
AC Voltage Calibrator	Fluke Model 5200A Calibrator or equivalent
10 dB Attenuator	Weinschel Model 50-10 or equivalent
Attenuator, 10:1	NIST Special Attenuator, dc-200 kHz $Z_{in} \approx 8$ kΩ, or equivalent
Calculator	Sharp Model El-5001 and Instructional Manual, or equivalent
Peak-to-peak Detector	NIST Special Detector
Digital Multimeter	Fluke Model 8506A or equivalent
10:1 Voltage Divider Probes with BNC tip adapters	Supplied by Oscilloscope Manufacturer
Amplifier, RF	ENI Model 3100 LA or equivalent
Terminator, 50 Ω, 40 Watt	NIST Supplied Fixture
BNC female to banana plug adapter	Pomona 1269
Male SMA to female BNC adapter	American 2082-2320 or equivalent
One 12" Coaxial Cable with Male BNC connectors	Pomona 4531-24
Female BNC to male N adapter	Pasternack PE9074 or equivalent

BNC Male to BNC Male Coaxial Cable 24 inches (61 cm) ea.	Pomona BNC-C-24 or equivalent
Precision Power Amplifier	Fluke 5205A or equivalent
Function Generator	HP 3325 Synthesizer/Function Generator or equivalent
Clock	General Electric 2908 or equivalent
LF Impedance Analyzer	HP 4192A or equivalent
Isolation Transformer	Topaz 91002-22 or equivalent
Three-wire-female to two-wire-male adapter	Carol, Type ME or equivalent
Pulse Generator	Picosecond Pulse Labs Model 2700 Pulse Generator or equivalent
20dB Attenuator	Weinschel Engineering Model 2-20 or equivalent
Signal Splitter	NIST Supplied
Female N to SMA Male Adapter	Pasternack PE9082 or equivalent
Male N to Female BNC Adapter	Pomona 3288 or equivalent
Two 12" Coaxial Cable (male BNC connectors)	Pomona 2249-C-12
SMA Male to BNC Female Adapter	Pasternack PE 9074 or equivalent
50 Ω Feedthrough Termination	Tektronix 011-0049-01 or equivalent
Meter Calibrator	Fluke Model 5101B or equivalent
BNC "T" Adapter - Female, Male, Female	Pomona 3285 or equivalent
BNC Male to BNC Male Coaxial Cable 18 inches (45.7 cm)	Pomona BNC-B-18 or equivalent
Signal Source, Power Line, 60 Hz	NIST Supplied
One 50 Ω BNC termination	Kings 1340-1-M06 or equivalent
Optical comparator (15X)	Bishop No. 3561 or equivalent
Pulse Generator, 2 ea.	Tektronix PG 508 or equivalent

Pulse Generator with
adjustable rise time

Hewlett-Packard Model 8082A

NBS-114A (REV. 2-80)

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10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)*

Electrical performance test procedures for a dc to 100 MHz storage oscilloscope were developed for the purpose of evaluating samples submitted by electronic instrument manufacturers in response to specifications issued by the U.S. Army Communications-Electronics Command. The detailed, step-by-step test procedures are based on the specifications supplied by the Army and include sample data sheets and tables for the recording of interim data and final test results.

This report discusses the measurement principles and techniques underlying the most significant procedures. In addition, the sources of measurement uncertainty are discussed.

12. KEY WORDS *(Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)*

acquisition memory; A/D converter; charge-coupled devices; digital storage oscilloscope; digital waveform recorder; flash converter; record length; sample/hold; test procedures; waveform processor; waveform sampling

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